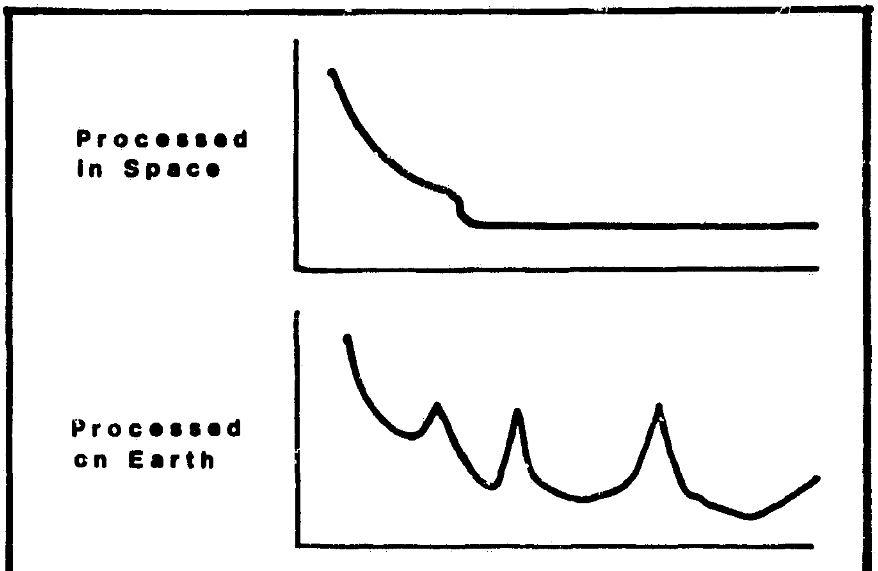
(NASA-CR-172762) USER REQUIREMENTS FOR THE COMMERCIALIZATION OF SPACE Final Report (Ecosystems International, Inc.) 138 p HC A07/MF A01 CSCL 22B

N83-28050

Unclas G3/15 12657

"USER REQUIREMENTS FOR THE COMMERCIALIZATION OF SPACE"

CONTRACT NASW-3674



Germanium Crystal Resistivity

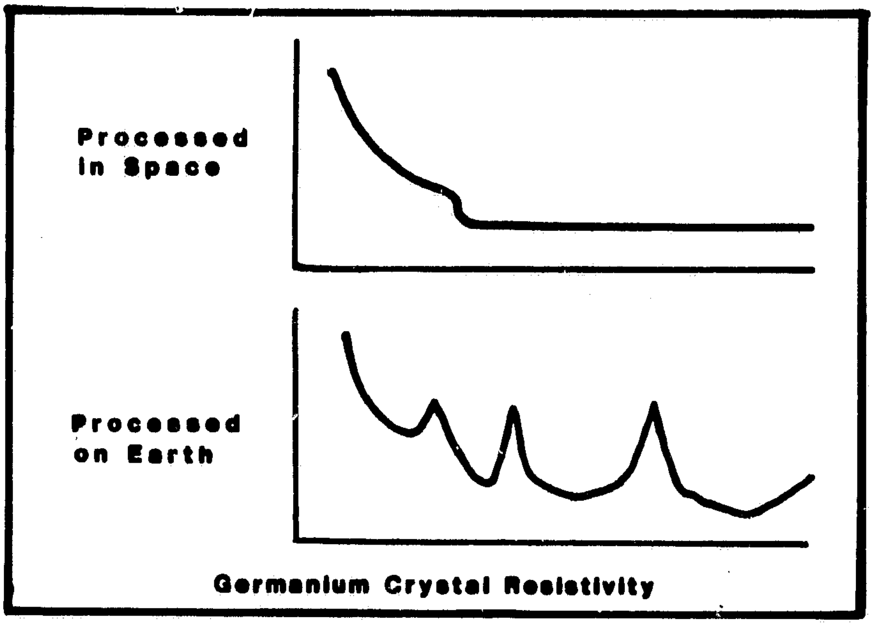
TASK 1 - FINAL REPORT
MAY 1983

PREPARED FOR:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

BY:
ECOSYSTEMS INTERNATIONAL, INC.
P.O. BOX 225
GAMBRILLS, MARYLAND 21054

"USER REQUIREMENTS FOR THE COMMERCIALIZATION OF SPACE"

CONTRACT NASW-3674



TASK 1 - FINAL REPORT
MAY 1983

PREPARED FOR:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON , D.C. 20546

BY:
ECOSYSTEMS INTERNATIONAL, INC.
P.O. BOX 225
GAMBRILLS, MARYLAND 21054

SPACE STATION COMMERCIALIZATION

TASK I - FINAL REPORT

CONTRACT NASW-3674

"USER REQUIREMENTS FOR THE COMMERCIALIZATION
OF SPACE"

APRIL 1983

PREPARED FOR:

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NASA HEADQUARTERS
CODE LG-2
WASHINGTON, D.C. 20546

BY:

ECOSYSTEMS INTERNATIONAL, INC.
P.O. BOX 225
GAMBRILLS, MARYLAND 21054

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (continued)

I - FOREWORD

This report is in fulfillment of Task I, "U.S. Non-Aerospace Industry User Requirements for Earth-Orbiting Space Station," of Contract NASW-3674 titled "User Requirements for the Commercialization of Space." The report was prepared by ECOsystems International, Inc. for the National Aeronautics and Space Administration Headquarters, Office of Industrial Affairs, Technology Utilization Division.

The overall goal of this 6-month effort, initiated November 1, 1982, was to assess the industrial potential of Materials Processing in Space (MPS). The establishment of such a potential can be directly related to the technological and economic payoff of specific MPS -- oriented space shuttle payloads, as well as to the cost effectiveness of a future National Space Station.

To support this goal, two objectives were pursued:

- To assess the degree of interest in MPS on the part of U.S. non-aerospace industry, and the potential obstacles to its utilization, by sampling selected U.S. industrial organizations.

- In support of the above assessment, to synthesize the status, results and promise of the art of MPS.

II - EXECUTIVE SUMMARY

2.0 BACKGROUND

This report represents the results of Task I entitled "U.S. Non-Aerospace Industry User Requirements for an Earth-Orbiting Space Station." This is part of an overall study of space commercialization being conducted by ECOsystems International, Inc. The focus of this study is to complement a number of parallel efforts underway under the auspices of various NASA Headquarters and Field Center organizations, by utilizing the approach of Application Development, to assess the interests and needs of the non/aerospace industries.

The first part of this Task was devoted to a collection and analysis of the results of the Materials Processing in Space (MPS) Program experimentation to date, in order to provide the technical basis for planned discussions with potential space commercialization user industries. This was an essential step since the Application Development technique requires a match of results with the user requirements of the organization where it is to be applied.

MPS Program results, however, were not readily available, making it difficult to complete this first step. In fact, it did not appear that a central point or organization could be addressed to elicit the required data.

Recourse to a number of NASA, University and Industrial sources of MPS data was then pursued vigorously, and a preliminary compilation of MPS results, still requiring completion, was developed. The collected data and information, albeit incomplete, was utilized as a basis for discussion with potential non-aerospace industry users.

The visits to the potential MPS user industries proved to be generally promising. The various R&D managers were quite aware of NASA's space commercialization activity, and interested in its promise. However, they were handicapped by available time to pursue in depth the application of MPS technology to their industry's requirements. Nevertheless, they evidenced a willingness to enter into further discussions if they were directed at areas of

technology of interest to their industries. For these reasons, this report contains a preliminary proposal for instituting a process that would accommodate these factors and still pursue NASA objectives: i.e., the establishment of a space commercialization constituency.

The conclusions and recommendations resulting from this Task are summarized as follows.

Conclusions

- The results of MPS investigations:

  - Are far more numerous and interesting than is commonly perceived;
  - Are not readily available in a centralized repository;
  - Are in a technical terminology not readily translatable to potential industrial users;
  - Need to be aggregated, compiled, made visible and extrapolated to valid commercial expectations and/or applications;
  - Show near-term promise for the manufacture of high value pharmaceuticals;
  - Show longer-term promise for the commercial development of materials requiring high degrees of structured control.

- A number of space experimentation apparatus have been developed. Most of these could also find use in terrestrial applications.

- Discussions with potential industrial users of MPS commercialization have shown:

  - Interest on the part of R&D managers;
  - MPS commercialization should be focused on areas of interest to each user;
  - A willingness to devote resources if they perceive real possibilities for space commercialization;

Recommendations

- A centralized data source of MPS program results should be established.
- MPS program results should be cast in terminology utilized by industry.
- MPS program results should be used to stimulate industrial thinking and latent creativity.
- Space experimental and processing apparatus should be characterized and included in commercialization endeavors.
- NASA space commercialization efforts should consider, in addition to MPS, the development and space deployment of large antenna structures for communications.
- An organized NASA space commercialization effort should be presented to potential space commercialization users.

III - BACKGROUND AND OBJECTIVES

3.0 BACKGROUND

Since the inception of its activities, NASA has pioneered the exploitation of unique physical properties of space for valuable industrial or public purposes. The implementation of this venture has given rise to well-known technological spinoffs -- communications satellites, atmosphere and earth observation space systems, and the growing industry of privately-owned space launchers and service satellites.

Throughout the last decade NASA has deepened its investigation of the applicability of certain properties of the space environment--primarily low gravity and vacuum--to industrial processes. Approximately 130 theoretical and experimental investigations of MPS have been performed to date, utilizing simulated space conditions, through use of drop facilities, aircraft in parabolic trajectories, coasting rockets, Apollo, Skylab, ASTP; and, recently, by exploiting the capabilities of the Space Shuttle.

NASA's latest planned endeavor is the deployment of an earth-orbiting space station. One of its important functions would be to serve as a test bed for MPS.

3.1 OBJECTIVES

The purpose of this effort is to characterize the interest on the part of U.S. non-aerospace industries in an earth-orbiting Space Station as an experimental facility.

Because of its status as an important and existing component of the potential commercial utilization of the Space Station, the MPS Program was selected for this investigation. Admittedly, there are a number of other areas associated with a Space Station that could also be addressed; yet ten years of experience in MPS work provide an excellent starting point.

The work plan of this Task included:

- The definition, qualification and quantification of the exploitable characteristics of the space environment through the efforts of several platforms currently used and planned for MPS utilization;
- A synthesis of results achieved thus far in NASA's MPS effort;
- A summary of the most promising payoffs anticipated from MPS, based upon the expected experimental and/or theoretical results achieved;
- A program of direct queries of selected U.S. industries, utilizing the information developed above, to assess industry's interest in, and potential problems with, the use of the space environment for profitable ventures.

During the course of this effort, it became apparent that the collection of the results from the MPS program was considerably more difficult and time consuming than had been anticipated. As a result, this report represents a partial synthesis of MPS research. In a later, follow-on phase of this Task, a complete summary of the research, augmented with a set of industry queries relating to MPS, is expected.

IV - STUDY METHODOLOGY

4.0 PURPOSE

The purpose of this study is to identify and define approaches to the commercialization of space.

In essence, commercialization of space involves developing the most cost effective technology that would induce a suitable segment of the industrial community to utilize the space environment for profitable purposes.

This entails two principal steps:

- Identifying the market
- Approaching and capturing the market

Since the advent of the industrial revolution, industry has developed, through repeated trial and error, methodologies for identifying and successfully approaching the market with its products and services. These methodologies are currently employed throughout industry. They are summarized following.

4.1 IDENTIFICATION OF THE MARKET

In industrial terminology, the population of potential customers is categorized in terms of "gross", "addressable" and "capturable" markets.

Gross market designates the totality of the possible customers for a given industry's products or services. Thus, for example, the gross market for MPS is the totality of industries which produce materials, and/or which process materials into added-value products. Through space commercialization, NASA provides the service to this market.

The addressable market, a sub-class of the gross market, consists of those potential customers whose requirements for products and/or services relate

closely to the products and/or services being offered by the "selling" industry. In the case of MPS, the addressable market includes industries which either:

- Produce products of high specific value i.e., high cost per unit weight;

- Engage in "exotic" processes whose intimate workings are not fully understood, and which could therefore benefit from additional insight through R&D efforts. In order for a process or product to be genuinely addressable to this market, its potential benefit must be expressable in terms of added potential sales from improved understanding of the process and consequent improved characteristics of the product, or more efficient performance of the process.

The capturable market is that segment of the addressable market who will actually purchase the products or services being offered. Thus, in the case of MPS, the capturable market represents those customers who can be expected to eventually benefit from MPS activities in concert with NASA. Note that the term "MPS activities" encompasses the end-to-end sequence of steps which begins with exploratory information exchanges and ends with purposeful experimentation and/or operations in the space environment.

Identification of the addressable and capturable markets is not an exact science, but is refined more precisely through experience. The addressable and capturable markets are statistical rather than deterministic concepts. They become deterministic, after the sales are actually completed.

4.2 APPROACH TO THE MARKET

A number of approaches have been developed by industry for capturing a suitable share of the addressable market. Existing approaches are variants of two methods:

- The Canvass method
- The Applications Development method

In the canvass approach, the seller seeks to elicit customers from within the base of the addressable market by offering his product or service to prospective customers on a statistical basis. The seller relies on the assumption that a certain percentage of interested prospects will be converted to "captured" customers. Because the basis for conversion from addressable to captured market is statistical, the assumption underlying the canvas approach is that the greater the number of prospects contacted, the greater the total number of customers will be.

In the applications development approach, the seller initially learns the prospective customer's business; he then market's his product or service in such a way as to provide specific economic advantages to the prospective buyer. In other words the seller does not rely on the prospective buyer to determine the usefulness of the offered product or service; rather he markets a "result", demonstrably benefitting the potential buyer, and predicated upon the buyer's use of the seller's product or service.

A key measure of the efficacy of a marketing approach is its cost/effectiveness, i.e., the ratio of sales to the cost of the resources expended to produce the sales.

The canvas method has proven to be most cost/effective in cases where the application of the product or service is either obvious or can readily be conceived by the prospective customer. This is the case, for example, of consumer products.

The applications development method has demonstrated maximum cost/effectiveness in cases where the product or service offered is difficult to relate to the prospective purchaser's advantage. This is generally true of complex, high technology processes. A typical example is offered by the introduction of computers during the fifties. The potential buyers had difficulty in relating the use of computers to their business needs. Thus, successful computer manufacturers approached their marketing problem by initially analyzing their prospect's operations. They then configured and presented their product in the manner of a service to increase the customer's productivity.

The applications development method has been selected for use in this study. While the canvass approach has classically been used, and is still being employed, in other efforts at space industrialization by NASA, the applications development approach should broaden the probability of achieving a wider base of interested industries. Moreover, it will allow NASA to compare the results achieved by the two methods.

Applied to this study, the applications development approach may be summarized in the following steps:

- Characterize the space environment and identify its unique properties;
- Isolate the exploitable effects of the environment in general and as specifically applied to MPS techniques;
- Derive and categorize the proven and potential applications of these effects;
- Identify corresponding candidate commercial products and processes;
- Identify specific industries as candidates for manufacturing these products or using these processes; and,
- Identify the mechanism whereby NASA can interface with candidate industries.

Initial contacts with prospective MPS customer industries suggested the overwhelming importance of proven, documented MPS results: or, as a minimum, of experimental data points and sound theoretical inferences. Thus, a major share of this effort was devoted to culling "results" from the available literature and from contacts with NASA centers. A synthesis of these results is presented in Section VIII.

To facilitate the success of discussions with various industries, a brochure, containing a short summary analysis of the MPS concepts and results to date, was conceived. This brochure would be utilized to stimulate the prospective user's interest in learning more of NASA's activities directed at the commercialization of space. A draft of a conceptual brochure is attached as Appendix C.

V - DATA SOURCES

5.0 APPROACH

The synthesis of MPS results was derived from the following major literature sources:

- Principal Investigator (PI) and Contractor Reports
- Flight Experiment Summaries and related NASA Technical Memoranda
- Bibliographies of MPS Literature
- Proceedings of Conferences
- Journal Articles.

Table 5-1 illustrates examples of the types of data and information available and obtained from the sources identified above. Complete listings are contained in the Bibliography, Appendix B.

In addition, significant data and information were gathered through a structured program of visits and personal discussions with high-level representatives of selected U.S. industries and with scientists and administrators working in the field.

5.1 RESULTS

The compilation of an orderly summary of MPS results was deemed of paramount importance to this effort, because it alone provides a solid base of facts upon which to construct an orderly application development approach to the space commercialization market. The results of this compilation are contained in Appendix C and discussed in Section VIII. NASA PI and Contractor Reports describing MPS experiments were sought throughout the course of this effort to obtain first-hand information regarding the results of past and ongoing experimental work. They proved to be difficult and time-consuming to obtain.

TABLE 5-1

EXAMPLES OF DATA SOURCES

I. Principal Investigator and Contractor Reports

- Gelles, S.H., E.W. Collings, W.H. Abbott, and R.E. Maringer, 1977. Analytical Study of Space Processing of Immiscible Materials for Superconductors and Electrical Contracts. NASA CR-150156.

II. Flight Experiment Summaries and Other NASA Technical Memoranda

- Naumann, R.J., 1979. Early Space Experiments in Materials Processing. NASA TM-78234

- Pentecost, E., 1982. Materials Processing in Space. Program Tasks. NASA TM-82496

III. NASA Bibliographies of MPS Literature

- Pentecost, E., 1982. Materials Processing in Space Bibliography. NASA TM-82466

IV. Proceedings of Conferences

- Marshal Space Flight Center, NASA, 1974. Proceedings of the Third Space Processing Symposium -- Skylab Results (2 volumes).

V. Journal Articles

- Covault, C., 1982. Payload Tied to Commercial Drug Goal. Aviation Week and Space Technology, May 31 Issue.

To circumvent this difficulty, several other types of publications were consulted. Among these, Experiment Summaries and NASA Technical Memoranda, while not describing results, at least outline experiment objectives. In addition, reports of experimental work published in the Proceedings of Conferences provided a valuable adjunct to PI Reports, although they provided fewer results. Journal articles, while not always strictly technical in nature, did supplement and complement direct sources of information.

The bulk of the information retrieved from NASA data bases, and the most useful to this work, was derived from NASA Technical Memoranda. These describe planned future experiments, some of the results of recent experiments, and the overall history of past experimentation. They encompass the Apollo, Spacelab, ASTP, and SPAR missions. They also include program plans and policy statements, summaries of program accomplishments and program tasks, and bibliographic documentation of program literature.

Journal articles provided summaries of the progress and some of the results of MPS. They address industrial uses of space, design and use of space factories, Space Shuttle MPS payloads, and technology transfer.

Selected books provided in depth historical perspective on such subjects as the American and Soviet MPS programs and space industrialization.

Statistical information was retrieved from Federal agencies including the Department of Commerce, the National Science Foundation, the General Accounting Office, and the Senate and House testimony on NASA appropriations.

To obtain a data base on material prices, catalogs of product lines and price lists were obtained from a variety of U.S. manufacturers, particularly in the areas of high value pharmaceuticals and chemicals.

A visit was conducted to the Marshall Space Flight Center. Extensive telephone contacts were made with the Lewis Research Center. The contacted individuals, who are currently involved in the MPS Program, provided excellent sources of information concerning past and on-going efforts related to potential commercialization experimentation. This enthusiastic support was of great value to the accomplishment of this Task.

An important segment of the information was gathered from a number of visits to carefully selected industries which were considered to represent potential space commercialization candidates. In every case, those contacted were high level technical managers who controlled all or a significant part of their corporate research programs. They were generally most receptive to pursuing further discussions on the MPS Program, as long as they were directed at what were considered to be areas within their business interest. The results of the visits are discussed in Section X.

VI - SPACE ENVIRONMENT PROPERTIES

6.0 EXPLOITABLE EFFECTS OF THE SPACE ENVIRONMENT

The Key to the commercialization of space is the definition of which of the space environment's characteristics are exploitable for commercial or industrial purposes. Specifically, which effects, induced by the environment, could be utilized to foster industrial processes or the understanding of how certain processes function on earth.

The exploitable effects of the Space environment are identified here by using the "Top-Down" approach. Through this approach, the basic properties of the space environment are first defined and their effects identified and quantified by comparison to those occurring in the earth's ground environment. Secondly, the current status of exploration or utilization of these effects for scientific or commercial purposes is explored. Thirdly, those effects that are unique to the Space environment, that is, not readily reproducible or impossible to reproduce on earth, are identified for further analysis.

The "Top-Down" tree is shown in Figure 6-1. Its explanation is provided in the subsections which follow, and in Section VIII.

6.1 ISOLATION OF THE PRINCIPAL EFFECTS OF THE SPACE ENVIRONMENT

The environment of a spacecraft in earth orbit is characterized by: (1) low gravity; (2) the rarefaction of the medium; (3) specific types of background radiation; and (4) synoptic overview of the earth's surface and atmosphere.

The latter effect, i.e., synoptic overview, has given rise to the important discipline of remote sensing from space. Because it is currently approaching successful commercialization, it lies beyond the scope of the present effort and will not be considered further in this report.

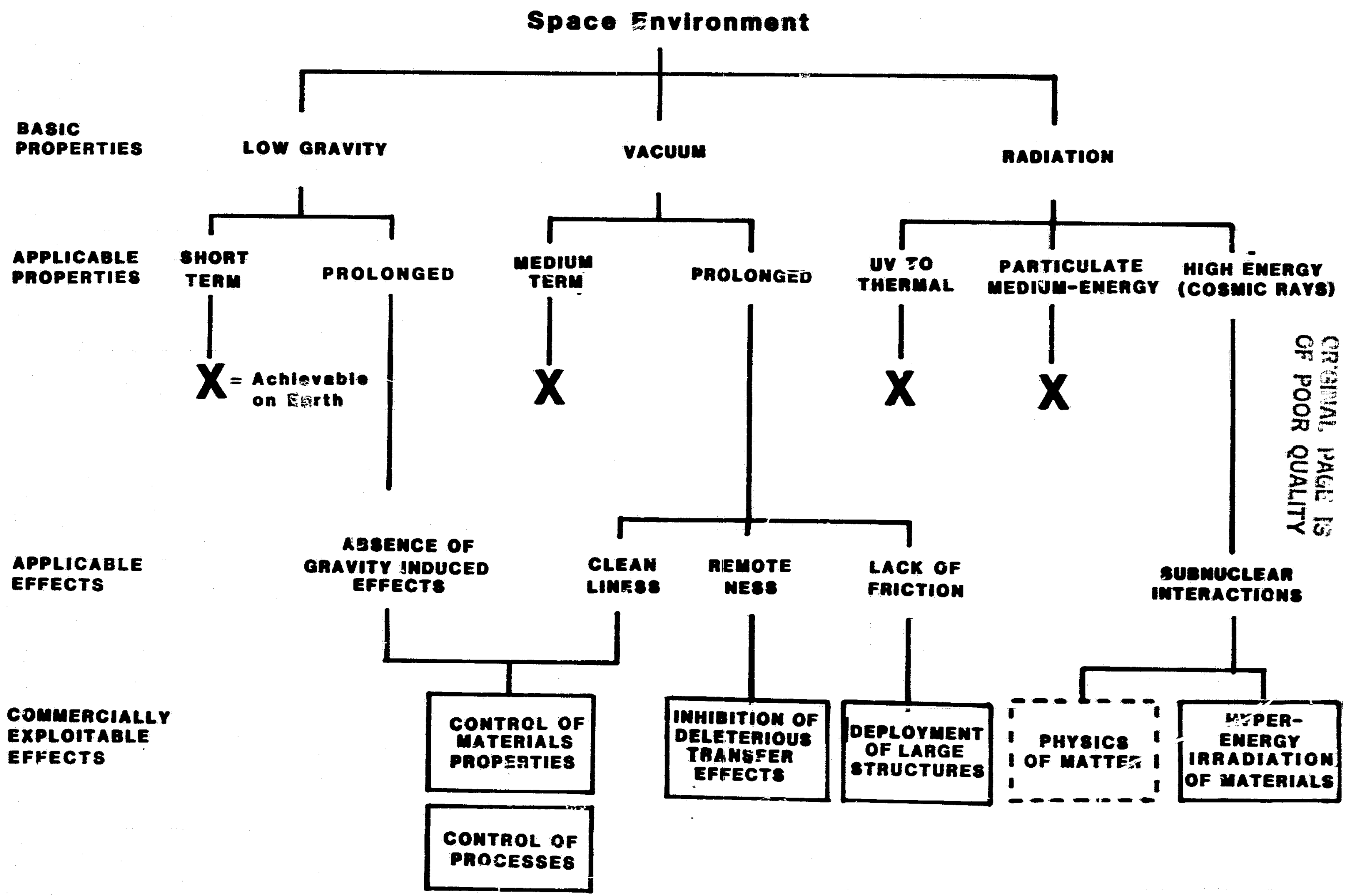


Figure 6 - 1 Unique Properties and Potential Applications of the Space Environment

6.2 LOW GRAVITY

In earth orbit, the centrifugal force acting upon the spacecraft equals the centripetal pull of gravity. This is to say, while gravity is active in earth orbit, its effect within the spacecraft is cancelled by virtue of the centrifugal force induced by the vehicle's orbital motion. Gravity is completely nullified, however, only at the vehicle's center of mass. It is small but measurable as one moves away from the vehicle's center of mass. In addition, small spurious forces are caused by orientation maneuvers (or by centrifugal forces due to spacecraft attitude motion if no orientation maneuvers are effected), and by any movements inside the vehicle. These spurious forces cause small departures from ideal zero-g conditions, known as g-jitter.

The presence of gravity gradients and of spurious forces limits the lower level of g forces available within a spacecraft. For this reason, the environment within the spacecraft is termed "micro-g" rather than "zero-g". Table 6-1 illustrates the residual g-levels induced by some of the phenomena which occur within the environment of spacecraft.

In ideal zero-gravity, the occurrence of important and unique phenomena has been hypothesized. These phenomena have been observed in the low gravity of orbiting spacecraft. For example, deformation due to hydrostatic pressure does not occur. Convection currents, one example being movements in fluids due to warmer portions rising and cooler portions sinking, are absent. Fluids do not separate due to density differences, which nullifies sedimentation and removes the effects of buoyancy.

Low levels of gravity for short time intervals are achievable by using earth-based methods. The oldest such method is the release of objects from tall structures. Galileo is reputed to have been the first to exploit this method scientifically by dropping objects from the leaning tower of Pisa. During the eighteenth and nineteenth century, "shot towers" were used to cast round lead pellets by dropping molten lead through a sieve onto an underlying tub of water. Famous among these is the Baltimore Shot Tower, built in 1829, which was used through the Civil War and until World War II to produce buckshot. See Figure 6-2.

TABLE 6-1

PRINCIPAL RESIDUAL G-LEVELS PRESENT
WITHIN SPACECRAFT IN LOW EARTH ORBIT (400 KM)

APPROXIMATE FORCES INDUCED BY:	EFFECT, KILOGALS
CONTINUOUS BELLY-DOWN ORIENTATION	$1.33 \times 10^{-7} \times d$
CONTINUOUS INERTIAL ORIENTATION	$3 \times 10^{-7} \times d \sin 2 \frac{t}{T}$
ATMOSPHERIC DRAG	$10^{-3} \frac{A}{W}$

Example: for $A = 100\ m^2$, $W = 100$ tons, $G \approx 10^{-6}$ Kilogals

d = distance from C.G., meters
T = orbital period, minutes
t = time elapsed, minutes
A = spacecraft frontal area, m^2
W = spacecraft weight, Kg

1 Kilogal $\cong$ 1 g

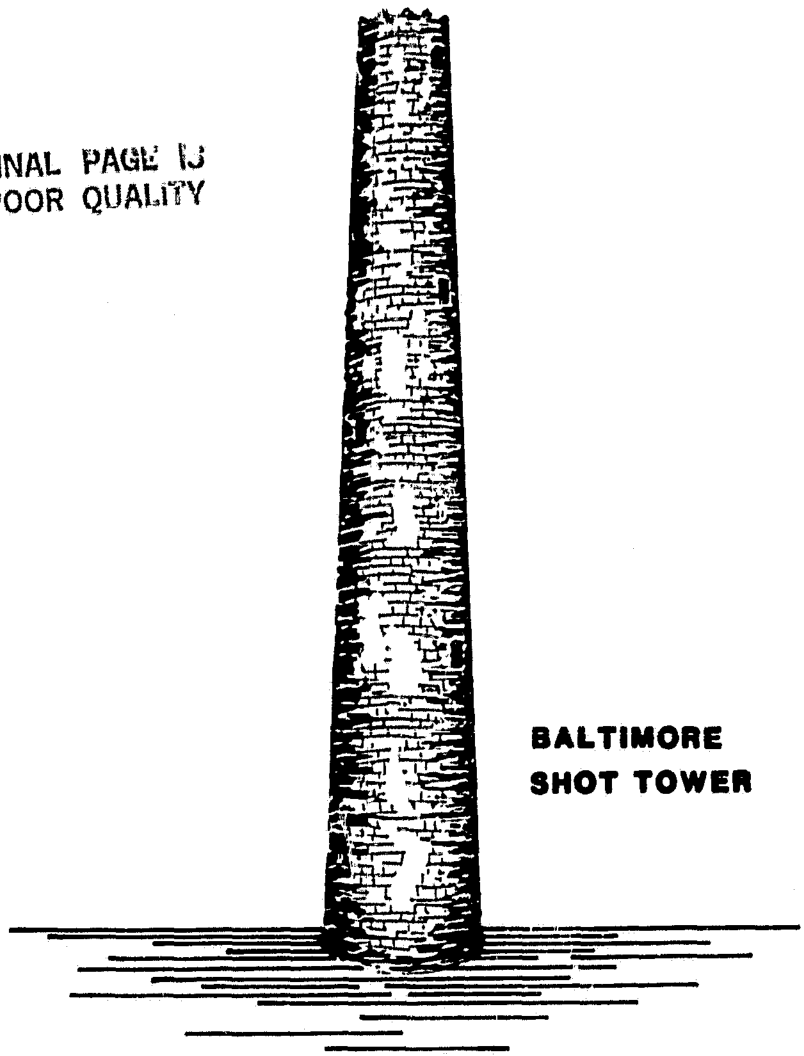


Figure 6-2.

A low gravity production facility built in 1829 and used during the Civil War and up to World War II to produce round shot by dropping molten lead 230 feet onto a vat of water. The molten lead solidified in free fall yielding spherical pellets of the desired caliber.

It is clear that the dropping of objects in the atmosphere does not simulate absolute zero-g, because of the drag effect of the air. Drag becomes more pronounced as the fall time (and the object's velocity) increases; for high fall heights and relatively small object sizes, a constant terminal velocity is reached, which nullifies the zero-g conditions altogether.

This problem can be solved by eliminating the atmospheric drag, through use of evacuated drop tubes. The cost of these structures has thus far limited their height. For example, the tallest evacuated tower in existence is that at the Marshall Space Flight Center (MSFC) in Huntsville, Alabama. Its 100 meter height allows free-fall durations of 4.2 seconds. Another method employed to minimize atmospheric drag is the use of aerodynamic shields. This is employed in the Lewis Research Center 130 meter drop facility. Other earth-bound methods, employed to produce low-g for short periods of time, are parabolic trajectories of aircraft, or coasting rockets.

All earth-based methods are characterized by short durations of low-g conditions. Low-g environments of short duration can be simulated on earth at relatively low cost.

This capability is reflected in Figure 6-1, in which the branch of the top-down tree connoting "short term low gravity" is terminated at the second level of the top-down chart.

Consideration of long term effects of low gravity is pursued at length in Section VIII.

6.3 THE RAREFIED MEDIUM

The earth orbital space medium, often designated as a void or vacuum, is not entirely empty. Matter, mostly a plasma, i.e., a gas of charged particles, is present in low densities. Dust, neutral hydrogen, and other chemical molecules are also present in lesser amounts.

The characteristics of the vacuum present in earth-orbital space are summarized in Figure 6-3. It is apparent that the level of vacuum available at low

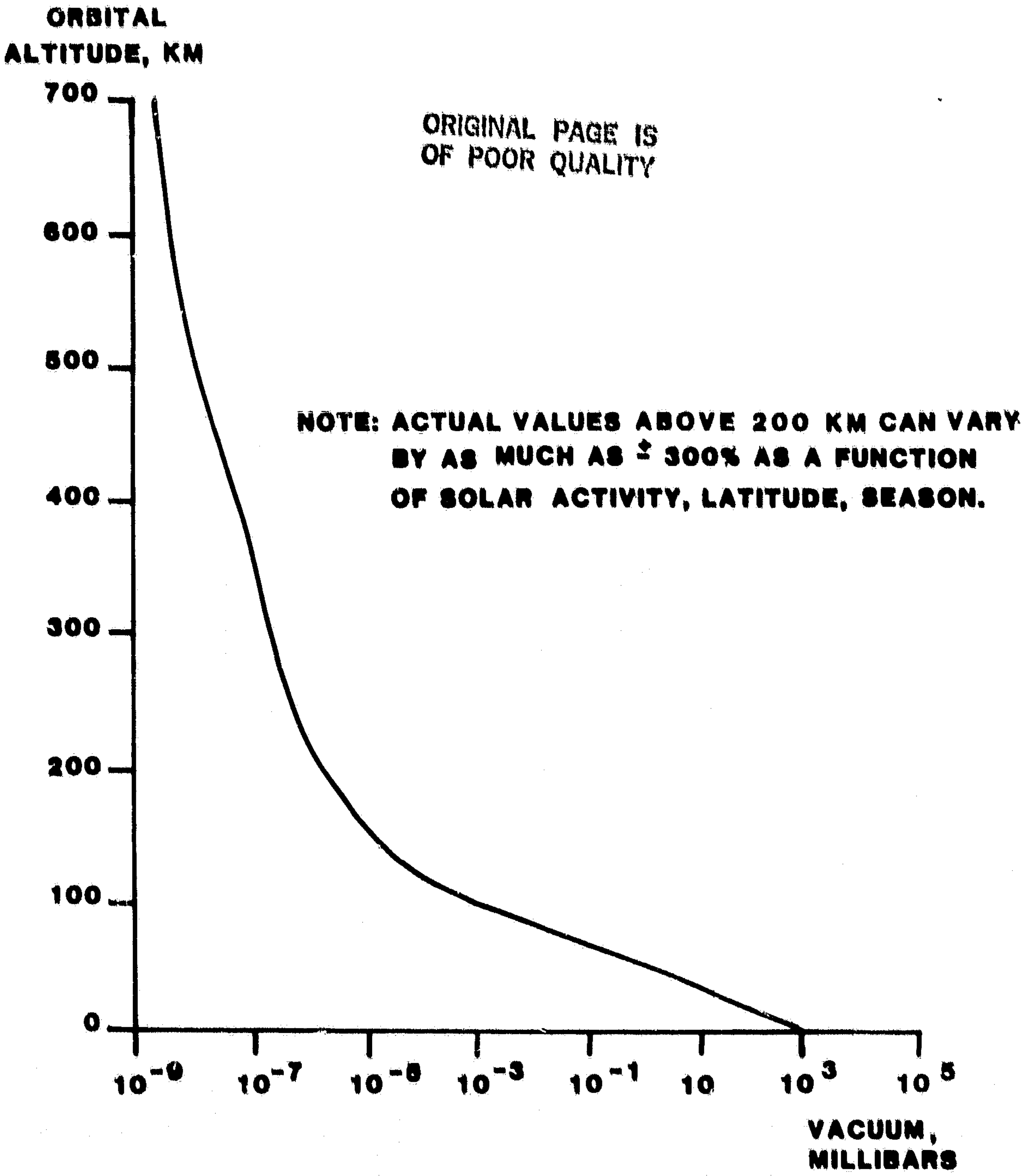


Figure 6-3.

Average Values of Vacuum Available in Earth Orbit.

orbital altitudes is not much higher than what is incorporated in commonplace objects, for example light bulbs or vacuum tubes (10^{-6} to 10^{-8} Torr).

A significant improvement in the level of vacuum can be attained in the wake of a "shield" moving at orbital velocities. The shield acts as a "sweeper" of the residual particles, as shown in Figure 6-4. The theoretical values of vacuum level, in proximity of such a shield, reach upwards of 10^{-17} Torr.

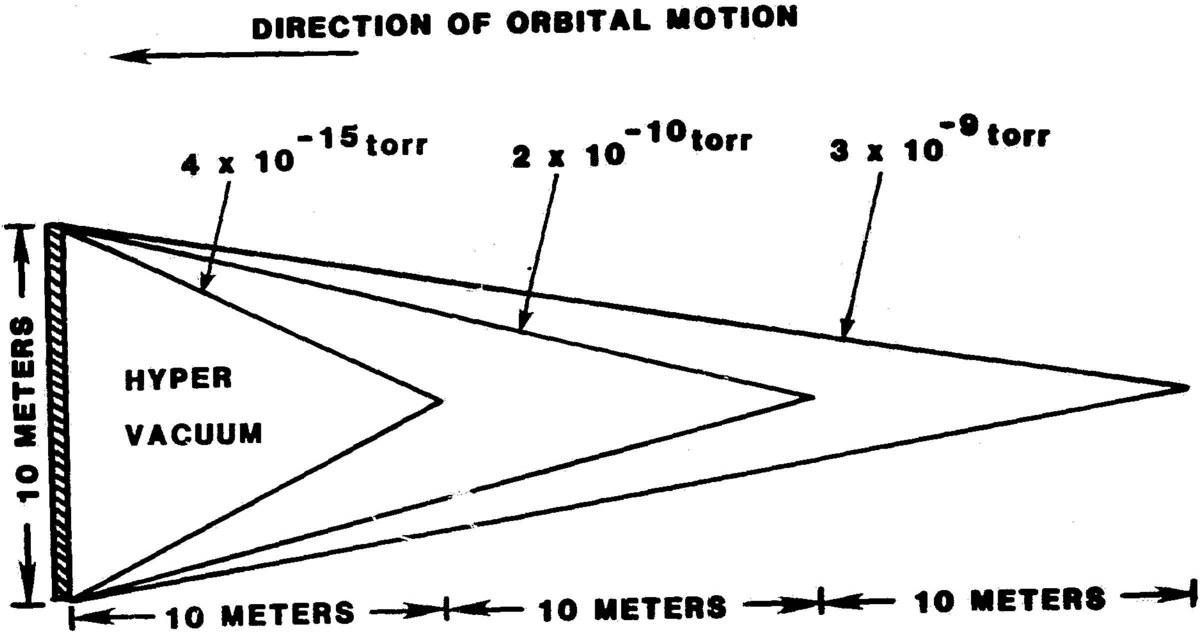
High levels of vacuum, for time spans ranging from hours to days, are achievable in earth-based vacuum chambers. Thus, in Figure 6-1 the corresponding branch of the top-down tree is terminated: only long duration vacuum is further considered.

With reference to Figure 6-1, three principal exploitable effects of the long-duration of a vacuum condition in space are:

- The tendency of unwanted materials to evaporate, yields a higher degree of cleanliness or purity among target materials.

- Since continued vacuum, over long distances, is a very good "isolator", the space environment is conducive to preventing deleterious substances from spilling over into the earth environment. This effect would apply to disease causing or toxic substances, such as pathogens or nuclear debris.

  With respect to nuclear debris, while it is not neutralized by vacuum per se, its attendant energy attenuates, in accordance with the inverse square law, by virtue of the distance between orbital altitudes and the earth's surface. It is reduced further by the absorbing effect of the atmosphere. Because of this isolating capability of space, the removal of nuclear debris, from the earth's surface to space, has been advocated in the past. International treaties, however, have prohibited this type of utilization of the space environment.



Vacuum Effect Behind a Moving Shield (Adapted from Naumann, Materials Processing in Space, Nasa SP-443.)

Figure 6-4.

- The absence of aerodynamic friction permits the deployment and maintenance of large structures, such as antennas for communications purposes.

6.4 RADIATION

Space is permeated by a wide spectrum of electromagnetic and particulate radiation. At sufficiently high orbital altitudes, this radiation is present in its pristine form, unimpeded and unabsorbed by the earth's atmosphere.

In earth orbit, the principal source of the electromagnetic radiation is the sun. The solar spectrum, observed above the atmosphere, is shown in Figure 6-5. The figure also compares the solar exo-atmospheric spectrum with the sun's spectrum observed at the earth's surface.

Note that the lower and upper wavelengths of the spectrum, namely the ultraviolet, x-ray, and the thermal infrared portions, are effectively filtered by the earth's atmosphere. However, these portions of the electromagnetic solar spectrum, which are absent at the earth's surface, can be simulated on the ground. Thus, the corresponding branch of the top-down tree is terminated in Figure 6-1.

The two principal sources of particulate radiation are the solar wind plasma and cosmic rays.

The solar wind is composed primarily of protons and electrons with ion traces of helium, oxygen, carbon and other elements. The kinetic energies of the particles composing the solar wind are relatively modest, well within the realm of what can be reproduced on earth. Consequently, the corresponding branch of the top-down tree of Figure 6-1 is terminated.

Cosmic rays, which originate in galactic space, consist of particles (protons and nucleons) possessing energies ranging upwards of 10^8 billion electron volts (Bev). These high-energy particles do not reach the earth's surface because they "split" and "degenerate" upon colliding with atmospheric molecules. Such high

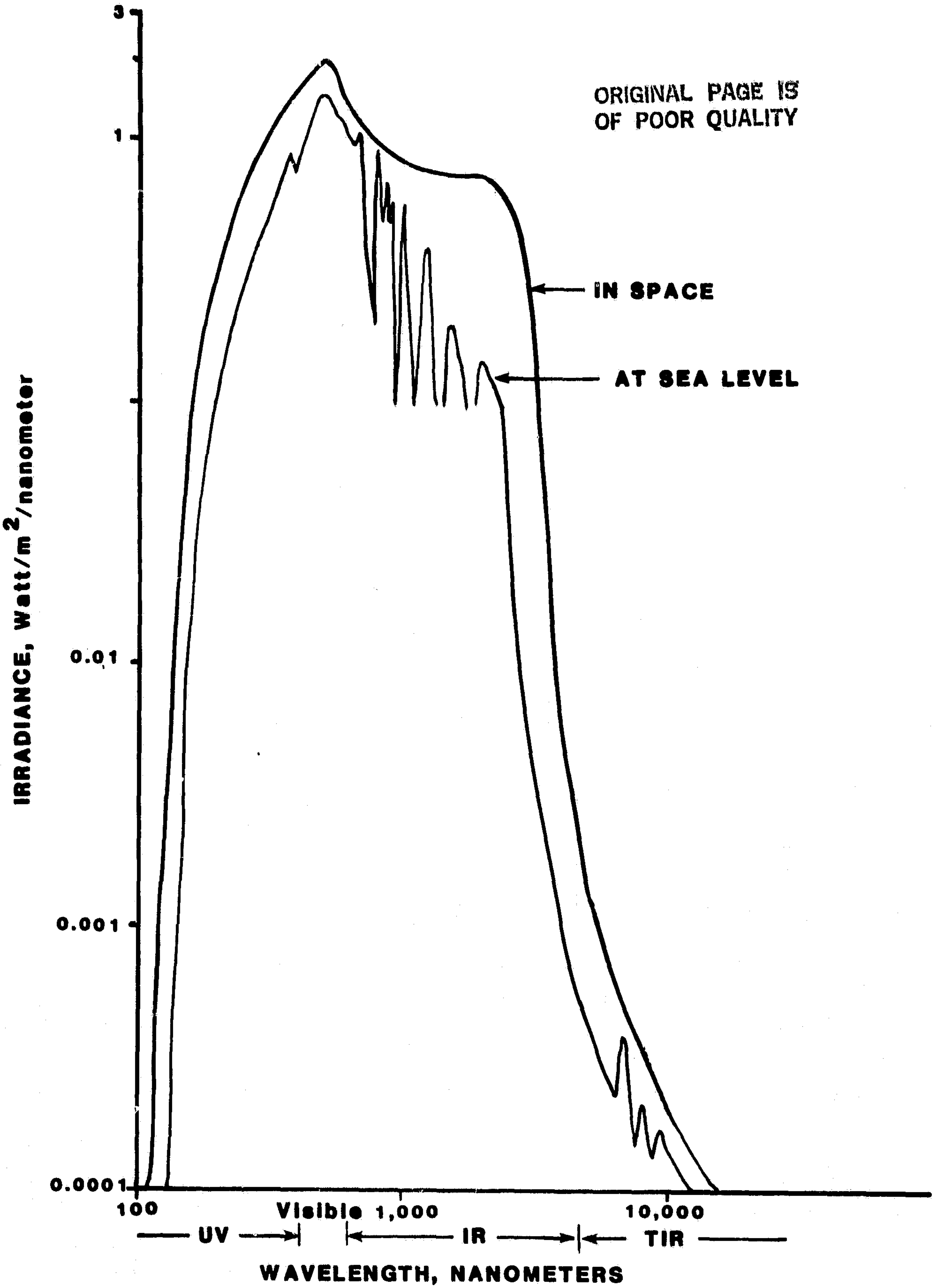


Figure 6-5 Spectral Irradiance of Sunlight

energies, at the present time, cannot be generated even in the best available ground-based particle accelerators. The most energetic of these accelerators is capable of 600 Bev, or several orders of magnitude less than the naturally occurring energetic cosmic rays.

Besides the scientific importance of cosmic rays in cosmological science, such high energy "bullets" are of great significance to physical research. While this physical research is not directly exploitable commercially, its potential future applicability to industry warrants the consideration of a space station as a setting for further research.

An additional potential application of energetic particles is the irradiation of materials. Irradiation is currently being performed industrially in such applications as the conditioning of elastometers and the preservation of foodstuffs. The space environment offers the opportunity of testing the effects of irradiation with hyper-energy particles.

The current status of actual exploration of the space environment for commercial purposes is discussed in the following section.

6.5 CURRENT STATUS OF EXPLOITATION OF SPACE EFFECTS

As was inferred in the previous section, the specific effects of interest to space commercialization are those that are not readily or cost-effectively reproduced on earth. Thus, those effects, summarized in Figure 6-1, which may be cost-effectively reproduced on earth, can be readily discounted. The effects of low gravity can be realized on earth for periods of a few minutes or shorter; thus only the freefall effects of low gravity in space, lasting for longer periods than are attainable on earth, are of interest. On earth vacuums of 10^{-9} to 10^{-12} Torr can be achieved for small volumes for upwards of 1000 hours; in space only vacuums for large volumes/and or longer durations are worth pursuing. Only extremely high-energy radiation above 600 Bev is currently not produced on earth; thus only high-energy cosmic rays are worth considering in space.

Since the beginning of the spaceflight program, various nations, principally the U.S. and U.S.S.R., have attempted to investigate and utilize the unique effects

of the space environment shown in Figure 6-1 and discussed above. Table 6-2 summarizes the current status of these efforts.

High-energy cosmic rays have been investigated by the Soviets, circa 1968, through their satellite "Proton", as a means to study the basic physics of matter. As predicted by U.S. scientists, this investigation confirmed the fact that cosmic rays are rare and widely scattered, that is to say few and far between and arriving from random directions. These were indifferent conclusions, not worth the expense of deploying a satellite.

The possibility of using cosmic rays for hyper-energy irradation of materials has not been explored further.

Isolation and remoteness are useful properties for inhibiting deleterious transfer effects, e.g. pathogenic, nuclear. As a result, studies have been conducted by NASA to investigate the use of space for the disposal of nuclear materials. These studies have shown that whereas the space environment can be a valid medium for disposal, by jettisoning of materials into the sun, the corresponding launch costs are excessively high, at least with the current state of the art. Further, the risk of launch aborts and consequent return of the hazardous material to earth has constituted a major deterrent to this type of utilization of the space environment.

The absence of aerodynamic friction is eminently conducive to the deployment and maintenance of space-based electromagnetic relay transceivers. Accordingly, satellite communications is currently a major industry in the U.S. and world-wide. Approximately 36 North-American Domsats are active at this time; 46 are scheduled for deployment by the end of 1984. Approximately 325 communication satellites are forecasted, worldwide, by 2000 A.D. All of these satellites currently utilize relatively small, state of the art antennas. The key question is what commercial benefit could accrue to the U.S. communications industry (currently grossing a yearly total of $100 billion) from the ability to add large antennas to these communication satellites. Approximately fifteen studies have been conducted by NASA on the engineering of large antenna structures. No analyses have been performed, however, regarding their potential commercial utility.

TABLE 6-2

STATUS OF DEVELOPMENT OF COMMERCIALLY EXPLOITABLE EFFECTS OF THE SPACE ENVIRONMENT

APPLICATION	STATUS
• HYPER-ENERGY IRRADIATION OF MATERIALS	• UNEXPLORED
• BASIC PHYSICS OF MATTER	• INVESTIGATED IN SOVIET "PROTON" SATELLITE • RESULTS: LIMITED VALUE DUE TO LOW DENSITY OF COSMIC RAYS
• INHIBITION OF DELETERIOUS TRANSFER EFFECTS	• NUCLEAR WASTE DISPOSAL INVESTIGATED • REJECTED DUE TO HIGH COST AND RISK OF CONTAMINATION FROM LAUNCH ABORTS
• DEPLOYMENT OF LARGE ANTENNA STRUCTURES	• APPROXIMATELY 15 ENGINEERING STUDIES PERFORMED • MARKET ANALYSIS NOT YET PERFORMED • POTENTIAL HIGH COMMERCIAL VALUE TO COMMUNICATION INDUSTRY
• CONTROL OF MATERIALS PROPERTIES AND CONTROL OF MATERIALS PROCESSES	• SUBJECT OF ONGOING MPS PROGRAMS IN U.S., U.S.S.R., EUROPE, JAPAN

The use of the space environment for Materials Processing in Space (MPS), which is the principal subject of this report, is currently being actively pursued by NASA, the European Space Agency, the U.S.S.R. and Japan. It is further treated in Section VIII.

VII - TEST FACILITIES

7.0 CONCEPT

As was observed in the previous Section, the current co mercially exploitable effects of the space environment are low gravity, vacuum and combinations of these.

To reiterate, low gravity can be simulated on earth for limited periods of time. The simplest method is to drop an object from an elevated structure, as was done in the past from "shot towers" -- or as is performed currently in evacuated drop facilities. Aircrafts in parabolic trajectories and rockets during their coasting phase generate low gravity conditions for limited time periods as well.

Because of their short duration, these low-g conditions are only of value for processing materials at a scale which allows the low gravity conditions to act throughout the material. Because of "process inertias" this implies s · all cales, i.e., small samples. Table 7-1 depicts typical sizes of materials which can be processed under these conditions.

For larger samples of industrial interest, the important characteristic of low-g processing is the product of the g-value and the duration of exposure to low-g.

By an analogous reasoning, the key characteristic of vacuum processing is the product of the level of vacuum and of the temporal exposure to this level of vacuum.

7.1 LOW GRAVITY

Several means are available for producing low-gravity, short of utilizing an orbiting space vehicle. In MSFC's 30 meter drop tower, gravities as low as 10^{-5}g

TABLE 7-1

TYPICAL SIZES OF MATERIALS SAMPLES WHICH CAN BE PROCESSED IN GROUND-BASED LOW-GRAVITY FACILITIES

FACILITY	LOW-g TIME SECONDS	SAMPLE SIZE GRAMS
30-METER DROP TUBE	2.4	0.5 TO 1
100-METER DROP TOWER	4.2	1 TO 5
AIRCRAFT	10 TO 60	5 TO 10
ROCKET	240 - 360	200 TO 300

Source: Commercial Applications Office, Marshall Space Flight Center

can be sustained for 2.4 seconds; in the 100 meter drop tower, similar gravity levels can be sustained for 4.2 seconds. In the Lewis drop facility, 5 seconds at 10^{-5}g are possible. Aircraft in parabolic trajectories can produce low gravity of 10^{-1}g for 40 seconds or 10^{-2}g for perhaps 10 seconds. Rockets can produce a gravity of 10^{-4}g for upwards of 4 minutes. The curve labeled "earth" in Figure 7-1 represents the envelope of these values.

The Shuttle, limited by its mission capabilities, can produce continuous gravity levels slightly less than 10^{-4}g for a maximum of four days. It can generate lower gravities (10^{-6}g) for shorter periods (order of 1 hour) with the help of special operational procedures. The estimated g-time duration Shuttle envelope is shown in Figure 7-1.

In theory, a space station could maintain continuous low gravity of at least 10^{-4}g for several months. Lower gravity levels of order 10^{-6}g could be achieved for shorter periods given the use of special operational procedures and a suitable location of the experimental equipment. The corresponding estimated g-time duration envelope is shown in Figure 7-1.

7.2 VACUUM

The technology for generating vacuum is well developed on earth. Pumping devices used to evacuate light bulbs and vacuum tubes maintain a vacuum of 10^{-6} to 10^{-8} Torr for periods of time as long as 1,000 hours. High-technology vacuum pumps can produce a vacuum of 10^{-16} Torr for up to one hour, see the curve labeled "earth" in Figure 7-2.

The Shuttle, because of its low orbiting altitude, can produce vacuums not greater than approximately 10^{-7} -- 10^{-8} Torr for up to 4 days (duration of a typical Space Shuttle mission).

Greater vacuums are obtainable at higher altitudes and/or in a Space Station equipped with special devices such as the wake shield, see Figure 6-4. By virtue of its longer mission and possibly higher orbital altitudes, the Space Station is estimated to be able to produce vacuums of 10^{-9} Torr for periods of 10,000 hours or more. Fitted with a wake shield, the Space Station should be able in theory to provide and maintain a vacuum of 10^{-16} Torr for upwards of 1,000 hours.

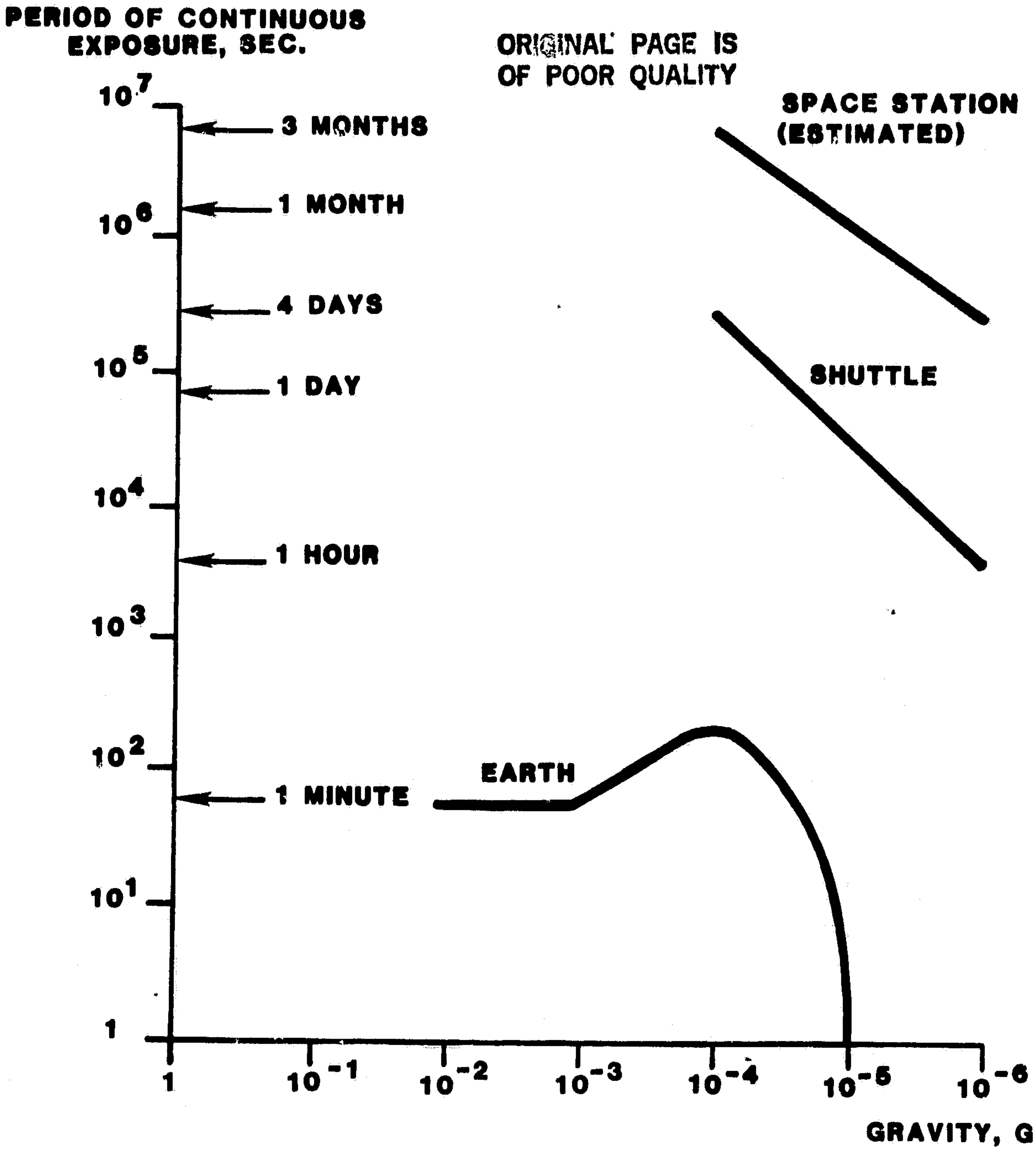


Figure 7-1.
Profile of Best Attainable Microgravity x Duration Levels.

ORIGINAL PAGE IS
OF POOR QUALITY

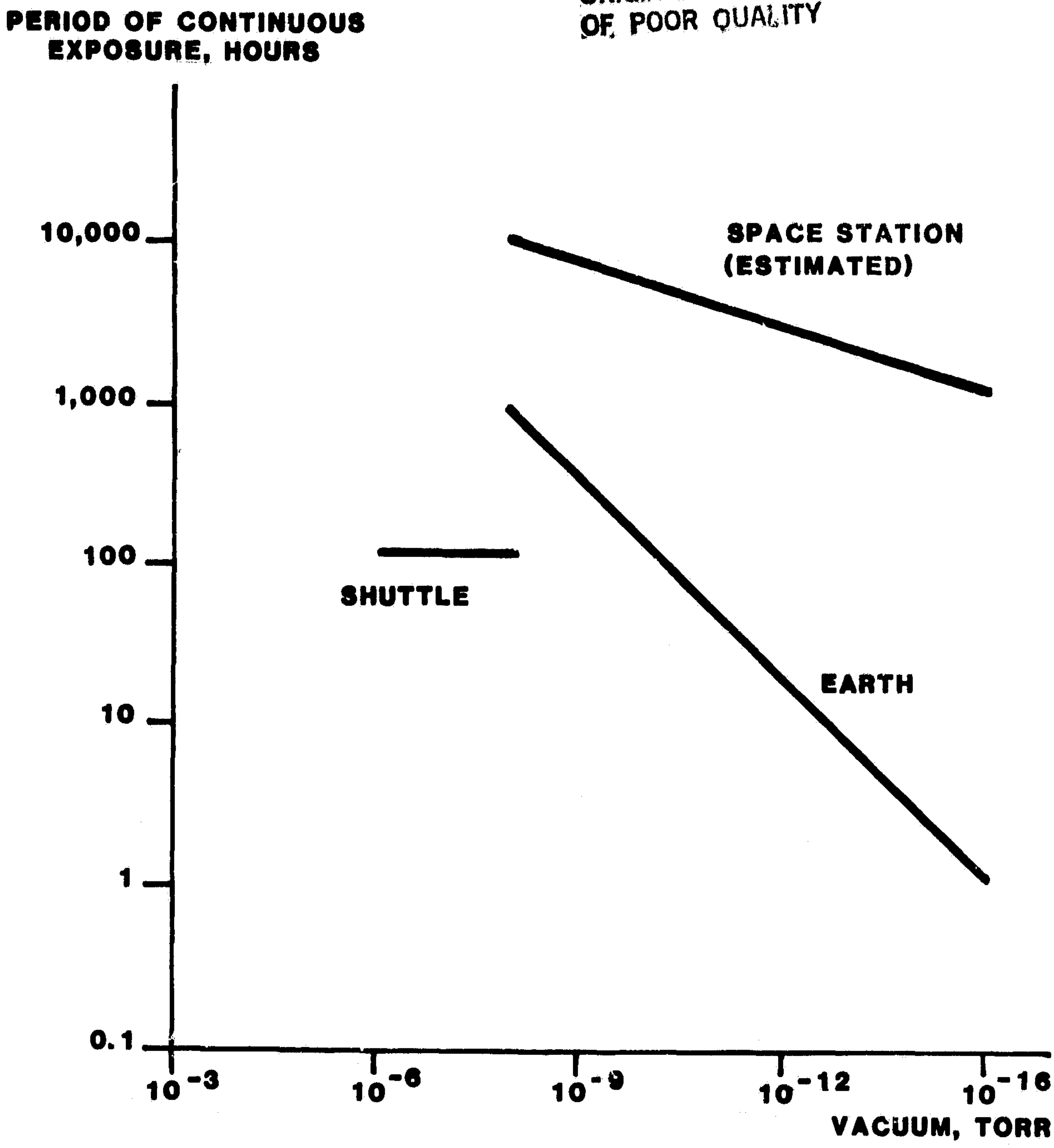


Figure 7-2.

Profile of Best Attainable Vacuum x Duration Levels.

7.3 COMBINATION OF GRAVITY AND VACUUM

From the preceding reasoning, it is apparent that the advantage to be gained from producing combinations of low-gravity and vacuum in space is in terms of the length of time in which both can be sustained simultaneously. On earth, it is difficult to produce the two effects concurrently for an appreciable length of time. The best obtainable non-orbiting facility is a coasting rocket, maintaining both low gravity (10^{-4}g for four minutes) and vacuum of up to 10^{-4} Torr, depending upon the altitude reached.

Estimated gravity-vacuum envelopes for both Shuttle and Space Station are shown in Figure 7-3.

7.4 THE FIGURE OF MERIT CONCEPT

The previous discussion leads to the desirability of defining a figure of merit reflecting the quality of available low-gravity and vacuum. The formulation of a proposed figure of merit is shown in Table 7-2. The proposed figure of merit is designed to increase as the effect-duration product becomes larger. Since the quality of the effects — gravity and vacuum — increases in inverse proportion to their magnitudes, it becomes natural to place the measures of the effects in the denominator. The combination of both is expressed as the "intersection" of the individual figures of merit for gravity and vacuum, i.e., the duration of simultaneous exposure to low gravity and vacuum.

Table 7-3 depicts computed and estimated figures of merit for various effects and facilities. The numbers presented show the great superiority of the space medium for using either or both vacuum and low-gravity. The space station, with a potential for long-term space missions, ranks highest among the facilities.

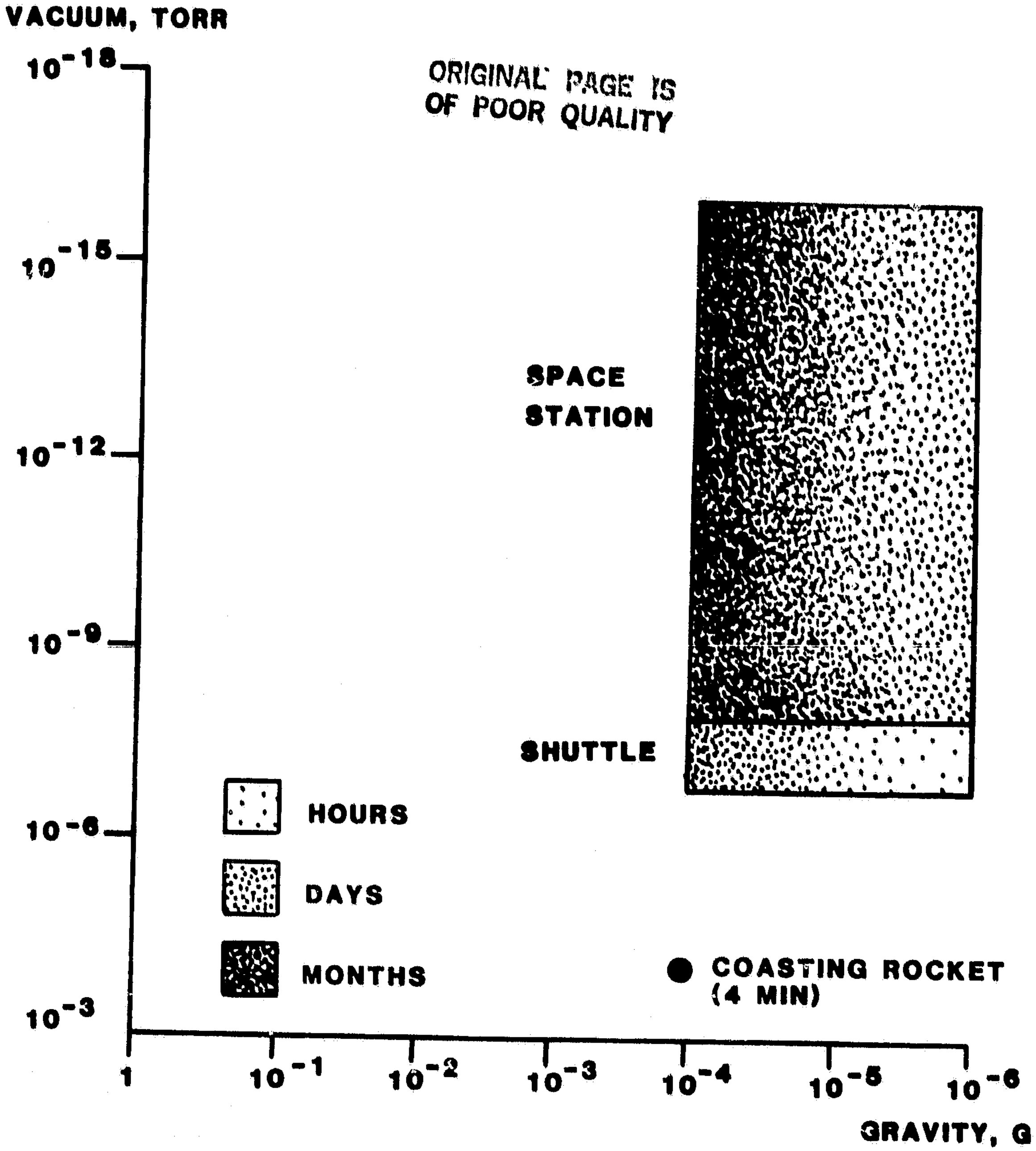


Figure 7-3.
Attainable G-Vacuum - Duration Envelopes.

TABLE 7-2

PROPOSED FIGURES OF MERIT FOR
LOW G AND VACUUM

EXPOSURE TO LOW-G:

$$Fg = \frac{\text{Duration of Exposure, Sec}}{\text{G-Level, Milligals}}$$

EXPOSURE TO VACUUM:

$$Fv = \frac{\text{Duration Of Exposure, Hours}}{\text{Vacuum Level, Pico Torr}}$$

COMBINED EXPOSURE:

$$Fgv = Fg \, \Omega \, Fv$$

Ω = "topological" intersection = duration of simultaneous exposure to low g and vacuum.

TABLE 7-3

COMPARATIVE FIGURES OF MERIT OF AVAILABLE AND PLANNED MPS FACILITIES

FACILITY	Fg	Fv	Fgv
AIRCRAFT	0.005	≈ 0	≈ 0
COASTING ROCKET	3	≈ 0	≈ 0
DROP TOWER	0.3	≈ 0	≈ 0
GROUND-BASED VACUUM CHAMBER	N.A.	UP TO 10^4	0
SHUTTLE	3,500	UP TO 0.1	
SPACE STATION (EST.)	UP TO 300,000	UP TO 10^8	

VIII - SYNTHESIS OF MPS APPLICATIONS

8.1 CATEGORIZATION OF MPS APPLICATIONS

Current literature categorizes MPS applications substantially as indicated in Table 8-1. This scheme of classification has developed piecemeal over the last decade and a half, as new applications were devised, gradually developed, and added to the inventory of actual or potential usages of MPS.

This categorization of MPS applications, while perfectly adequate and comprehensible to scientists and engineers familiar with the field, presents some difficulties when submitted to industrial R&D managers not already conversant with MPS lore. One of its problems is that it intermixes products, processing techniques and apparatus.

For example, with reference to Table 8-1, the term "containerless processing" connotes a technique rather than a product. The term evinces at first blush exciting vistas of unique and valuable capabilities. Upon further consideration, however, the recipient is unavoidably forced to ask himself "how does containerless processing relate to my specific processes or products?"

The answer is not easily obtained: it requires a considerable depth of analysis, and the required time is seldom available to the busy industrial manager.

Analogously, the category "crystal growth and solidification" connotes a set of techniques—in this case, not obviously and immediately unique to the space environment-- which are common to the manufacture of diverse products, e.g. semiconductors, special optical substances. The recipient needs to engage in the mental process of assessing how this technique, when effected in space, does differ advantageously from conventional methods of growing crystals.

A more succinct grouping of the categories shown in Table 8-1 has recently appeared in the literature, see Table 8-2. While it has the virtue of conciseness, this abbreviated grouping still presents a problem for the industrial user, namely relating MPS categories to the specific products generated by his concern.

TABLE 8-I

CONVENTIONAL CATEGORIZATION OF MPS APPLICATIONS

- Crystal Growth and Solidification
- Electrokinetic Separation
- Fluid Mechanics
- Composites
- Suspensions
- Immiscible Systems
- Solidification Front Interactions
- Monodispersed Latex Spheres
- Critical Phase Transformations
- Floating Zones
- Distortional Influences
- Containerless Processing
- Degassing and Desorption
- Extensive Electron Beam Processing

TABLE 8-2

ABBREVIATED CONVENTIONAL CATEGORIZATION OF MPS APPLICATIONS

- Crystal growth
- Solidification of Metals, Alloys and Composites
- Fluids, Transports, and Chemical Processes
- Ultra High Vacuum and Containerless Processing Technologies

The above observations, derived from interface with R&D managers of potential MPS user industries, see Sections X and XI, indicate the desirability of developing a categorization scheme suitable for facile communication with commercial users and capable of providing a visible and useful synthesis of the functions which the space environment offers to the field of materials processing.

8.2 ALTERNATE CATEGORIZATIONS

As is the case with all new sciences, the young lore of MPS has grown during its short lifetime through an inductive approach. Diverse findings and ideas accreted to the body of MPS knowledge as they gradually emerged.

The natural evolution of a maturing science is the eventual transition from the inductive to the deductive approach, i.e., from the particular to the general, from a collection of facts to the definition of underlying and unifying "laws".

The advantage of the deductive approach is that it permits the philosophically satisfying process of explaining the available facts; further, and more useful in practice, it allows the prediction of the ultimate consequences of the "laws" and thus serves to guide subsequent research towards approaching the ultimate limits of which the technology is capable.

At this time, MPS appears to be sufficiently mature to lend itself to such a process of deductive categorization.

A deductive categorization of MPS functions should begin with first principles, i.e., with the ultimate objectives of MPS; it should progress subsequently to its applications, through analysis of the exploitable properties of the space environment, following an ordered sequence of logical steps.

The end applications derived from the approach should satisfy five criteria:

- Orthogonality, i.e., the applications should not overlap each other
- Comprehensiveness, i.e., the method should encompass the spectrum of current and potential future applications

- Traceability, i.e., the genealogy of each application should be unequivocally relatable to the objectives through each step of the logic

- Visibility, i.e., the logic should allow facile communication and understanding on the part of recipients not fully conversant with the field

- Significance, i.e., the end results should be expressible in terms related to economic value

Figure 8-1 illustrates a scheme of classification derived from the top-down approach introduced in Section 6, see Figure 6-1.

As can be seen by comparing Figure 8-1 and Table 8-1, this scheme reconciles the current categorization with a deductive classification. The scheme represents a science-oriented approach, useful to technologists for categorizing actual or potential MPS products in terms of the space environmental effect, or combination of effects, utilized to generate them.

A more industrially-oriented categorization is depicted in Figure 8-2. Its logic derives from two top-level objectives:

- The development of materials having specified characteristics

- The development of materials-producing processes which are economically worthwhile, i.e., efficient in terms of the required resources

These two objectives have been the goal and have permeated the evolution of materials processing throughout mankind's history.

In pursuit of the first objective, for example, stone implements have been gradually replaced by bronze, iron and then steel; bark bowls have given way to earthenware, porcelain, and plastics; medicinal herbs were superseded by potions,

ORIGINAL PAGE IS
OF POOR QUALITY

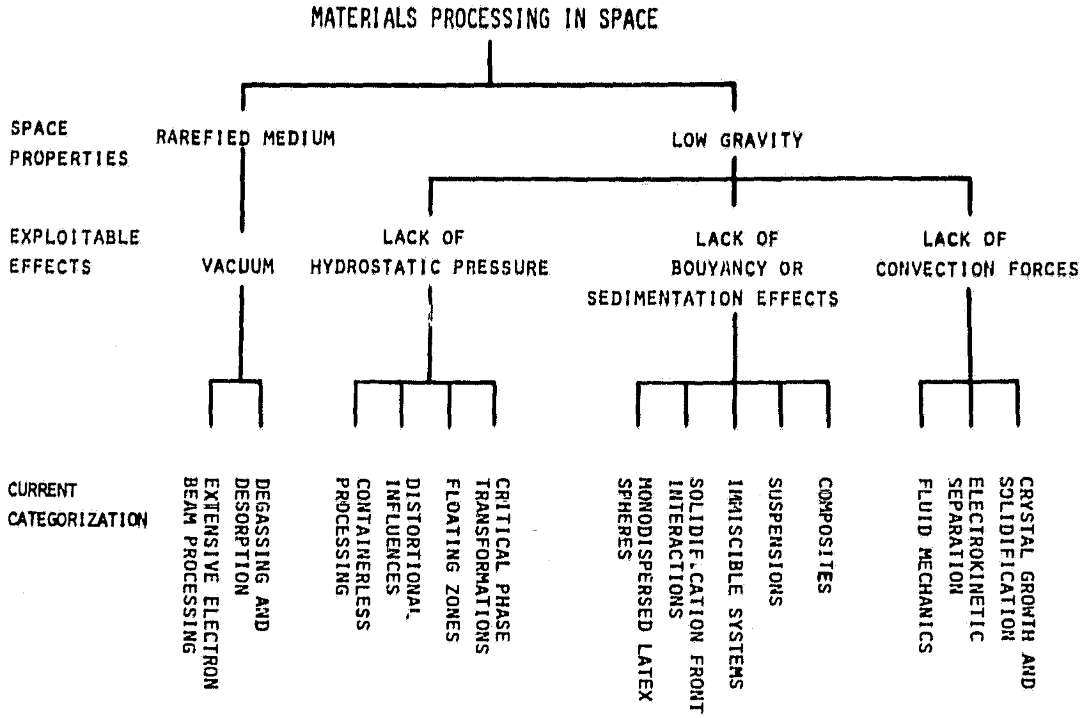
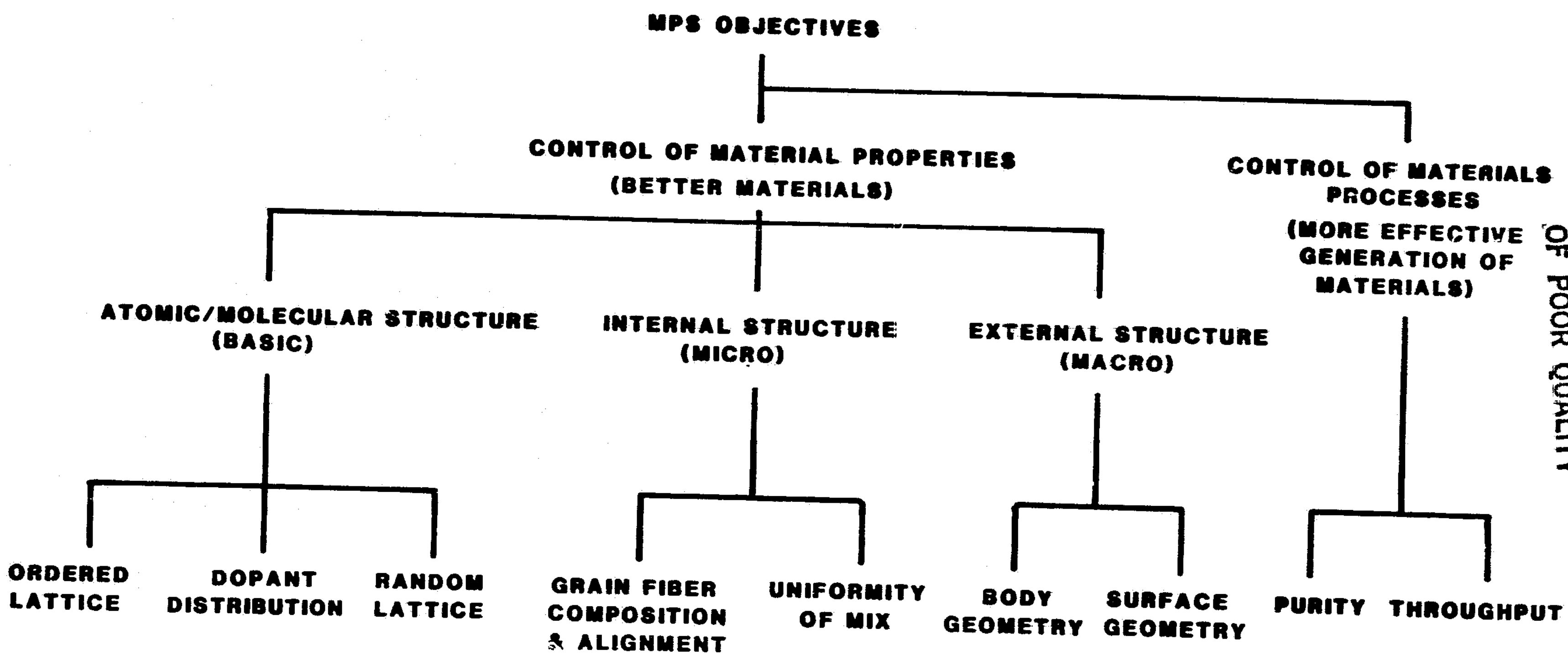


Figure 8-1. Reconciliation of Current Categorizations of MPS Applications with Top-Down Approach



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 8-2. Materials Processing in Space — Categorization by Objectives

inorganic pharmaceuticals and finally antibiotics. In all cases, new developments in materials technology have occurred through improved understanding of how to control the properties of the corresponding substances.

The second objective listed above addresses the obvious requirement for economic efficiency. The occasional lumps of iron produced in Sumerian copper smelters became of practical use only after the Hittites discovered how to produce the metal at sufficiently low cost to warrant replacing their army's bronze swords. Aluminum, worth more than gold before the inception of this century, became a major element of modern technology only after the economical process of cryolite electrolysis was developed.

The two objectives stated above correspond to the two top-level branches shown in the logic tree of Figure 8-2, labeled respectively: Control of Materials Properties and Control of Materials Processes.

Modern materials technology seeks to control the properties of materials at three levels:

- The atomic or molecular structure -- Control of materials properties at this level represents the highest degree of control currently practically possible.* Control of materials structure at this level is ultimately desirable for most materials. However, because of its difficulty and expense, it is currently exercised for products only where it is of paramount necessity.

  Control at the molecular level is required: 1) for generating highly ordered lattices needed, for example, as building substrata for semiconductors; 2) for achieving distributions of suitable "impurities" (dopants) in exact proportions and at precisely determined locations within ordered lattices, required for producing high-quality semiconductors; or 3) for accomplishing highly random distributions of atoms and molecules, needed for producing the

---

* Control at the subatomic level is a logical next step of the advancing MPS technology. It has not as yet appeared in current literature.

category of materials conventionally known as "glasses".

- <u>Internal macromolecular structure</u> — Control at this level involves the distribution or alignment of groups of molecules. This type of control is attempted in the metallurgical industry, for example to achieve desired proportions and spatial distributions of hard perlite grains within softer iron-carbon matrices. Concentration of hard grains at the surface of the internal parts of machines provides resistance to wear; the softer material throughout the rest of the machine provides resilience to impact. Also, grain and fiber control is used to achieve uniform or pre-assigned distributions, each having specified grain sizes, of two or more materials which are immiscible in bulk.

- <u>External structure</u> -- Control at this level defines the shape of macroscale objects. The object of this type of control is to provide exact geometrical shapes — e.g., perfect spheres — and/or preassigned surface finishes. Examples are ball bearings, microspheres, electrical contacts.

It is clear that the three levels of control defined above can be effected jointly.

For example, machine parts almost always couple controlled internal grain structure with precise external dimensions. Such combinations are conventionally achieved by serial processing. One of the exciting promises of MPS is the possibility of its accomplishment by means of a single processing operation -- for example, through containerless processing.

In addition to striving for control of materials properties, modern industrial technology seeks to improve continuously the economics of materials processes. This important facet of MPS is indicated by the right-hand branch of the logic tree of Figure 8-2.

MPS technology offers two opportunities for improving processes:

o Manufacturing in the space environment

o Experimenting in the space environment

The first opportunity applies to situations where the value of the end-product is sufficiently high, and the improvement of processing efficiency sufficiently significant, as to more than offset the transportation costs to and from space. The second opportunity applies in cases where three driving factors are present: 1) conventional terrestrial manufacturing processes are imperfectly understood; 2) improved understanding can lead to significant reduction in the costs of the product; and 3) the sales of the products are sufficiently conspicuous so that even modest savings in processing costs more than offset the expense of space experimentation.

The classification proposed and shown in Figure 8-2 appears to meet the criteria of usefulness outlined previously. The classification scheme is orthogonal; there is no overlap among functions. The classification is comprehensive because all classes of materials, e.g. glasses, semiconductors, ceramics, metals, composites, polymers and complex biochemicals, fit into one or more of the control schemes. Traceability is preserved because each material can be connected to a specific class of control and related back to the objectives of MPS.

In the writer's experience, this type of categorization, by virtue of its orientation towards "what to do", serves to focus the industrial manager's perception onto the MPS application of particular interest to his concern.

Note that the proposed categorization eliminates items which connote techniques or apparatus, e.g., "containerless processing." The latter fall within the realm of "how to do" rather than "what to do." They belong in a subsequent phase of MPS consideration, dealing with which specific choice of technique to employ in attempting to achieve the industrial "customer's" materials control objective.

8.3 COMMERCIALIZATION – ORIENTED RESULTS OF MPS PROGRAM TO DATE

To date, approximately 130 MPS-oriented experiments and tests have been conducted by the U.S., for a total of approximately 30 hours of low-g exposure. These experiments and tests are summarized in Appendix A. The summarization

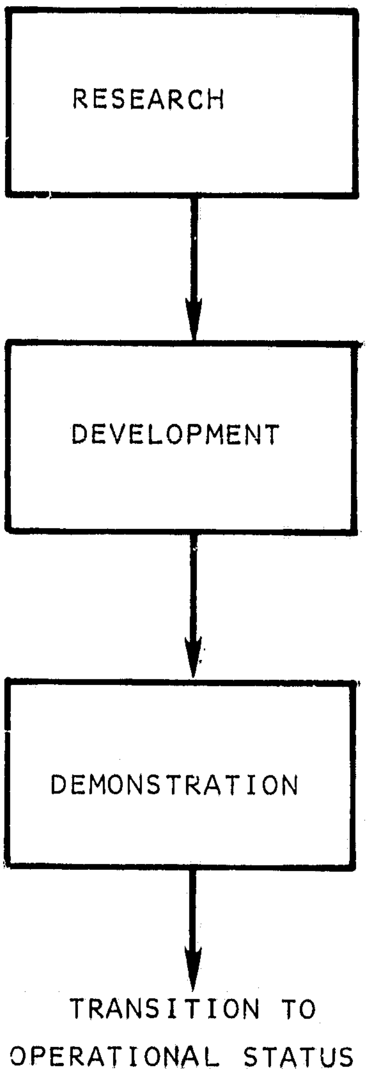
was derived from existing published literature. For each investigation the summary in Appendix A provides the following information:

- Title of the Investigation as assigned in the literature
- Name and organization of the Principal Investigator (PI)
- Vehicle on which the investigation was conducted, e.g., ground, rocket, Skylab
- Time frame when the investigation was conducted
- Objective of the investigation
- Results accomplished

Note that the column labeled "results" in Appendix A is filled only for approximately 15% of the investigations. This apparent dearth of results is common to other PI programs performed in the past. It is understandable from the cautious nature of scientific investigators: frequently, scientists are reluctant to qualify the mere achievement of progress as a result.

For purposes of commercialization, it is important, however, to somehow leapfrog the pace of progress. This can be accomplished by inferring expected or potential results from the investigations, to the extent that such inferences are warranted by the investigation's scientific content or demonstrable promise. A methodology for extrapolating results from investigation reports is indicated later in this Section.

Of significance to the overall MPS program is the current status of the investigations, in terms of progress through the successive steps of research, development and demonstration. The scheme of categorization is shown in Figure 8-3. With reference to the Figure, note that the goal of research is to define, modify and verify a concept which holds promise for MPS. The objective of development is both descriptive and predictive, resulting in the verification of a concept suitable for commercial demonstrations or suggesting new approaches for research to modify the concept. The purpose of commercial demonstration is to



- CONCEPT DEFINITION
- THEORETICAL MODELING
- EXPERIMENT DESIGN
- EXPERIMENTAL VERIFICATION ON GROUND

- DESIGN OF TEST APPARATUS
- REPLICABLE EXPERIMENTATION TO VALIDATE APPLICABILITY TO SPACE PROCESSING
- EXPERIMENTAL APPLICATION OF THEORY TO DEMONSTRATE PREDICTABILITY OF RESULTS ACROSS RANGE OF CONDITIONS/ MATERIALS

- DESIGN OF PILOT UNIT
- OPERATION OF PILOT UNIT
- ECONOMIC ANALYSIS TO VERIFY COMMERCIAL POTENTIAL
- MARKET STIMULATION

Figure 8-3. Stages of Progress Towards Commercialization

show that the processing concept works in a larger scale, that processing is economically attractive and that the market exists for the corresponding product.

The approximately 130 investigations listed in Appendix A were categorized as to progress, as shown in Figure 8-4. Note that only two experiments could be classified as pilot-scale demonstrations. The one listed in the column "absence of convection" demonstrated free-flow electrophoresis. The other listed in the column "absence of buoyancy-sedimentation" demonstrated the manufacture of large monodispersed latex spheres.

Comparison of the categorization by objective of Figure 8-.2 and the categorization as to progress of Figure 8-4 leads to a broad hypothetical inference relative to potential commercialization of MPS materials. Electrophoresis, which appears closest to commercialization in Figure 8-4 (under the heading "absence of convection" and "pilot demo") fits under the right-most column, "control of material processes", of Figure 8-2. The microsphere experiment, also closest to commercialization, see Figure 8-4 (under the headings "absence of buoyancy sedimentation" and "pilot demo", fits in Figure 8-2 within "body geometry" under "external structure." Both these categories connote control of materials properties on the largest (macro) scale. Experience thus appears to indicate that control is most difficult for the smaller scales, less difficult as the scale of the product increases. It could be hypothesized that products candidates for commercialization will likely reach fruition in those applications requiring control of the macroscopic structure of a material or process.

Almost two-thirds of the investigations tabulated in Figure 8-4 lie in the research category. For most of these, the Principal Investigators did not provide explicit results. As indicated previously, a suitable methodology can be used for inferring results. This methodology is shown in Section 8.4 and is tested on a sample basis in Section 8.5. A major thrust of the follow-on phase of this effort will be to extrapolate further results from the investigations documented in Appendix A.

		RESEARCH	DEVELOPMENT		DEMONSTRATION	
			EXPERIM. DATA	EXPERIM. APPARATUS	PILOT DEMO	PROCESSING APPARATUS
LOW GRAVITY	ABSENCE OF HYDROSTATIC PRESSURE	23	7	5	-	2
	ABSENCE OF CONVECTION	33	19	-	1	2
	ABSENCE OF BOUYANCY/ SEDIMENTA TION	27	15	-	1	
RAREFIED MEDIUM	VACUUM	3	-	-	-	

Figure 8-4. MPS Experimentation Categorized by Stage of Progress Towards Commercialization
(Through September 1982)

8.4 METHODOLOGY FOR SYNTHESIS OF RESULTS

The methodology follows the approach outlined below.

Step A. The MPS investigations are subdivided by categories following the approach presented in Figure 8-3. Analysis of the approximately 130 investigations summarized in Appendix A indicates that they fall into three categories in descending order of achievement of "hard" results:

1) Demonstrations of processes. These are tests, or series of tests, aimed at defining the technical and economic characteristics of specific MPS processes and/or products; for example, the series of electrophoresis processing tests performed on the Space Shuttle.

2) Experimental data points collected in a low-gravity (and/or vacuum) facility. In this category fall experiments aimed at demonstrating specific effects of the space environment, postulated by theory; for example, Skylab tests to validate the fact that convection does not operate under weightless conditions

3) Theoretical analyses -- for example, the extensive series of researches performed by the Bureau of Standards under contract to NASA

Step B. For eacn category of investigation defined above, the corresponding report material is analyzed to determine which of the following elements of information have been yielded by each investigation:

1) Results indicating a major technical and a promising economic advantage of processing in the space environment;

2) Results indicating an experimentally proven advantage of the space environment;

3) Results indicating a definite theoretical advantage of the space environment;

4) Inconclusive results observed, despite an apparently correct experimental procedure;

5) Inconclusive results due to faulty experimental procedure. Typical of this case is the documented occurrence, or the suspicion of occurrence, of spurious spacecraft maneuvers which have interfered with an experiment. An example is the "sphere forming" low-gravity experiment in Skylab.

6) Definitively negative results. This would imply that the hypothesis postulated for the investigation has unquestionably been proved faulty. Note that very few, if any, of the available experimental findings are expected to fall into this category.

Step C. For each of the above categories (A) and elements of information (B), the reported "positive" and "promising" results, e.g., those corresponding to items B1, B2, B3 above, will be extrapolated, consistent with scientific correctness, to indicate the "expected potential" from the particular techniques used in the investigation under analysis.

Step D. The positive and promising results -- be they extrapolated from theory, or from experimental data points, or from process tests -- are integrated with critiques and personal communications achieved from interfacing with NASA Centers and Principal Investigators.

8.5 INITIAL TEST OF THE METHODOLOGY FOR SYNTHESIS OF RESULTS

Six investigations, among the approximately 130 reported in Appendix A, were selected and categorized according to the methodology established above. The criteria for choosing these experiments were: (1) the original literature version had already indicated "results", albeit expressed in scientific terms rather than in commercially oriented format. This made the application of the methodology more straightforward than if no results at all had been indicated; (2) the investigations fell in categories B1, B2, B3, as defined in the previous Section, i.e., they could be classified as "positive" or "promising"; (3) the investigation reports were supported by additional documentation, allowing ancillary confirmation of the extrapolations performed.

The six investigations thus selected are summarized in Table 8-3. Note the difference between the contents of the column labeled "Extrapolated Results" in Table 8-3 and those in the column labeled "Results" in the corresponding investigations presented in Appendix A.

The last column of Table 8-3, labeled "Criterion #", refers to the specific step of progress indicated in the methodology outlined in the preceding Section.

The inferred commercialization potentials, corresponding to the six investigations exemplified in Table 8-3, are listed in Table 8-4.

TABLE 8-3

EXAMPLES OF RESULTS RELATIVE TO COMMERCIALIZATION

CODE	TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	EXTRAPOLATED RESULTS	CRITERION #
76	Zero-G Processing of Magnets	Dr. D.J. Larson Grumman Aerospace Corporation	Apollo-Soyuz		To investigate the effects of reduction of gravitationally dependent elemental segregation and convection in the solidification of high-coercive-strength magnetic composites in low-g.	MnBi rods made in space were finer and more evenly distributed in the B_i matrix than ground samples. The low-temperature coercive strength of this magnet was among the strongest ever measured.	B.3
80	Electrophoresis Technology	Dr. R.E.Allen MSCF Dr. G.H.Barlow Abbot Labs	Apollo-Soyuz		To demonstrate the feasibility of free-flow electrophoresis in a static column by using the low-g environment to suppress the convective mixing associated with joule heating.	Free column electrophoresis was demonstrated despite a failure in the experimental apparatus.	B.1
108	Immiscible Alloy Compositions	Mr. J.L.Reger TWR Systems Group Redondo Beach, CA 90278	Skylab		To thermally process ampoules containing materials exhibiting either liquid or solid state immiscibility in order to determine the properties of the composite material.	Samples of an Au-Ge alloy processed in space exhibited superconductivity of 1.5K while ground-manufactured control samples did not.	B.3
110	Preparation of Silicon Carbide Whisker Reinforced Silver Composite Material in a Weightless Environment	Tomoyaske Kawada National Research Institute for Metals 2-3-12, Nakameguro Meguro-ku, Tokyo Japan	Skylab		To obtain Ag and SiC whisker composites with high density and uniform distribution of whiskers by heating and pressurizing sintered products above the melting point of Ag in a weightless environment.	The whiskers were fairly uniformly distributed in flight samples, whereas they tended to cluster near the top of the ground-manufactured samples. Microhardness was found uniform throughout the flight samples; but only so near the top of ground samples where whiskers tended to congregate. Bend load tests also showed that low-g samples evinced large amounts of ductility, whereas ground samples exhibited brittle fracture.	B.1
112	Seeded, Containerless Solidification of Indium Antimonide	Dr. J.U. Walter University of Alabama in Huntsville Sponsor: NASA	Skylab		To investigate the feasibility of containerless processing of single crystals in space; and demonstrate potential of space for producing them.	Highly perfect single crystals can be prepared by seeded, and by containerless solidification; large crystal could be prepared by this technique as well. Production of homogeneously doped single crystals by containerless techniques appears to be feasible.	B.2
117	Steady State and Segregation Under Zero Gravity InSb	Prof. A.F. Witt MIT Cambridge, Mass. 02139	Skylab		To confirm advantages of zero gravity environment; to obtain basic data on solidifcation to explore the feasibility of electronic materials processing in space.	Dopant distribution was found to be extremely homogeneous.	B.2

ORIGINAL PAGE IS OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 8-4

INFERRED COMMERCIALIZATION POTENTIAL
OF SELECTED SAMPLE INVESTIGATIONS

Code	Title	Inferred Potential
76	Zero-G Processing of Magnets	The advantage of manufacturing very strong magnets in space
80	Electrophoresis Technology	The commercial means for processing pharmaceuticals in space
108	Immiscible Alloy Compositions	Manufacturing materials in space which cannot be made on earth
110	Preparation of a Silicon Carbide	Manufacturing products composed of ultra strong composite materials
112	Seeded Containerless Processing	Manufacturing large single crystals with special optical properties, such as IR detectors
117	Steady State and Segregation	The capacity to manufacture superior semiconductors in the space environment

IX - AREAS OF PROMISE

9.0 PURPOSE

The object of the previous section was the objective depiction of the current status of the MPS program. Despite the fact that the majority of the investigations performed thus far do not state explicit accomplishments, it is possible to extrapolate their findings onto reasonably creditable expectations of results. Examples are provided in the previous Section; see Table 8-3. The bulk of this effort is slated for the subsequent phase of this work.

The purpose of this section is to provide examples of initial assessments of products and processes which portend the highest promise for the commercial application of MPS.

Processes and products of highest promise shown here are of two types:

- Applications extrapolated from results achieved in past experimentation

- Applications which belong in new areas, not heretofore addressed, but whose theoretical foundations portend significant advances in materials properties.

9.1 CRITERIA FOR SELECTION

The reason for commercial processing of materials in space is ultimately economic. If a product can be manufactured more economically in space, or if its economic usefulness and profit potential on earth can be increased by what is learned in space, it becomes cost effective to process materials or experiment with materials processes in the space environment. Consequently, the field of commercially-oriented MPS applications falls into three broad categories:

(1) manufacture in space of products under conditions where the economics are favorable (see further discussion of pharmaceuticals);

(2) processing in space of materials which can be projected to have unique commercial value on earth (see further discussion of immiscibles);

(3) conducting in-space research and development on materials and processes to improve commercial processing on earth.

The economic considerations impose the following criteria for screening products and processes which are potential candidates for MPS.

- High value to weight ratio
  Processing in space is expensive. Current estimates of the gross processing cost, including tare, range from $500,000 to $1,400,000 per kilogram.

For example, the round-trip cost of Shuttle transportation is approximately $2,000 per kilogram. The gross cost of processing includes the carriage of the tares, i.e., the cost of transporting processing equipment and materials storage facilities. It also includes the O&M costs for the materials processing facilities, and a proportionate share of the Shuttle's O&M costs.

Whereas the exact processing cost will depend upon the specific product and process employed, Figure 9-1 examplifies the estimated gross production costs for a typical product.*

It is obvious that candidate materials for commercial manufacturing in space should be sufficiently light to minimize transportation charges, while valuable enough to insure that the market price offsets the costs attributable to transportation. An example of such products is pharmaceuticals, whose prices range up to billions of dollars per kilogram.

- Potential for process improvement
  The value of a product should increase as its processing improves, or decrease in cost as processing becomes more efficient.

---

* "Commercial Materials Processing in Low-g (MPLG): Overview of Commercialization Activities", a briefing by Marshall Space Flight Center, presented at NASA Headquarters on March 7, 1983.

ORIGINAL PAGE IS
OF POOR QUALITY

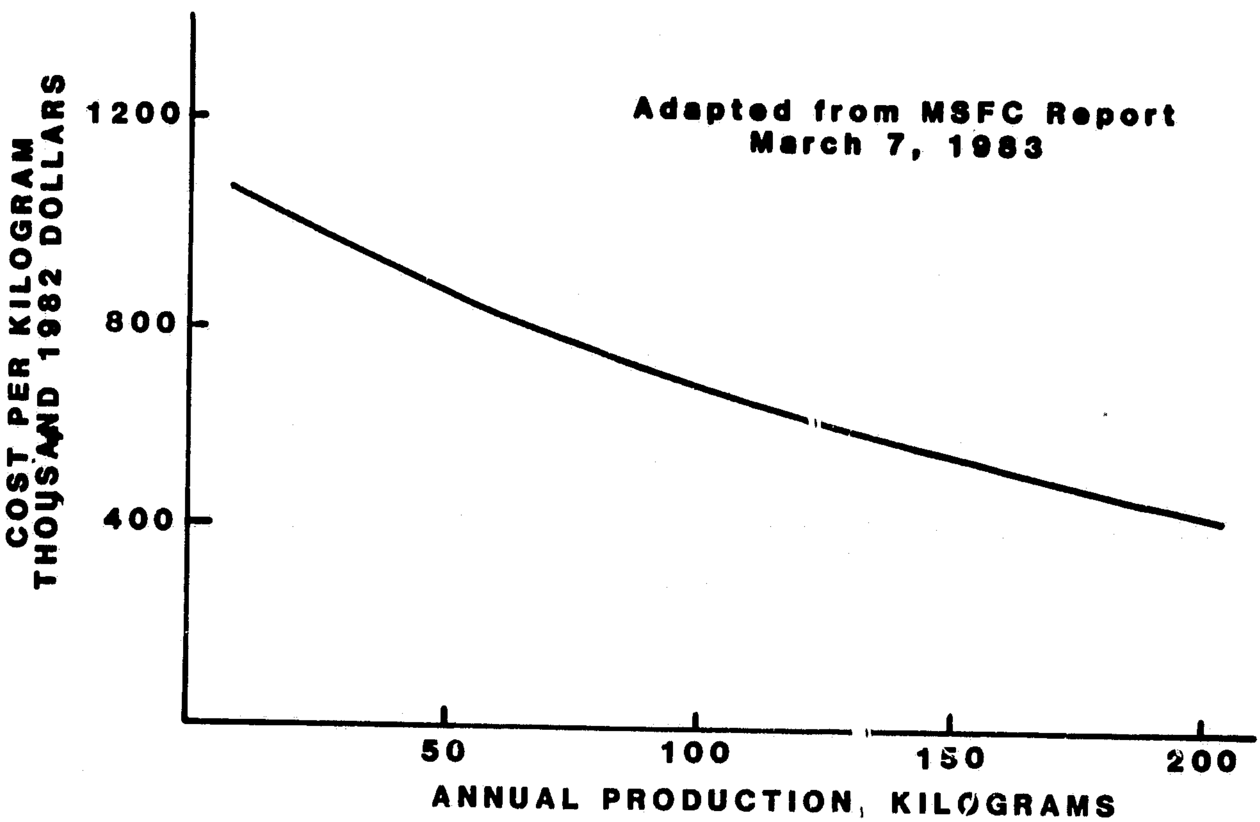


Figure 9-1. Typical Space-Based Production Costs (Monodispersed Latex Spheres)

It has been suggested that a greater than 400 to 1 improvement in effectiveness of space over terrestial processing is a realistic threshold for selecting candidate processes for MPS.*

- Production of unique products
  If a product cannot be adequately processed on earth, but is amenable to space processing, it warrants consideration as a candidate for MPS.

Due to the unique genesis of such a product, earth-manufactured products would not be competitive with it. The economic criterion would be the revenue which the product could command.

A possible example would be large bodies of metallic glasses. Current earth-based technology is adequate for manufacturing small beads of metallic glasses only. However, the market for such products has as yet not been established.

9.2 EXAMPLES OF PRODUCTS WITH COMMERCIAL PROMISE

The methodology based upon state-of-progress, indicated in the previous Section, can be coupled to the criteria for selection developed above -- i.e., high value to weight ratio, potential for process improvement, production of unique products -- to extrapolate commercial applications from selected MPS investigations.

In this section, five examples are developed. Four pertain to extrapolation of past investigations: one, dealing with strength of materials, is derived from theoretical considerations.

The value of such extrapolations, performed with the proper balance between fantasy and scientific grounding, is that they provide an imaginative yet pragmatic outlook as to what is possible. Experience shows that this approach is most valuable in stimulating the thinking of industrial R&D managers.

---

* ibid. MSFC briefing.

The development of the five examples selected follows.

9.2.1 PHARMACEUTICALS

"Pharmaceuticals" or interchangeably "drugs" are defined, in their broadest sense, as substances that are used in (1) the diagnosis, treatment, mitigation or prevention of disease, abnormal physical states or symptoms thereof; and (2) restoring, correcting or modifying organic functions.

Major groups of drugs include:

- anesthetics - drugs causing a loss of sense perception
- antiseptics and germicides - drugs safeguarding against infection
- chemotherapeutic drugs - chemicals used to treat or investigate a variety of diseases such as malaria, and abnormal physical states such as cancer
- hormones - glandular excretions affecting growth and other bodily functions
- tranquilizers - drugs inducing a calm mental state
- vitamins - complex organic substances essential in small amounts to sustain a variety of body funtions essential or important to health.

Drugs are classified in the trade in one of three ways:

- pharmacologically, i.e. based upon which bodily functions they do affect
- by therapeutic uses, i.e. according to what conditions they can impact or treat

- by chemical group

Pharmacological and therapeutic classifications do not necessarily relate unequivocally to the physical process whereby a drug is produced. Chemical classifications are better suited to this end. Thus the classification used following is by chemical group.

Pharmaceuticals comprise a large and diverse universe of ethical drugs, biochemicals and immunochemicals.

- The term "ethical drug" refers to all drugs of whatever origin whose use conforms to the standards of medical practice. Examples of drugs not considered "ethical" in this country are heroin, LSD and other drugs for which there is no recognized therapeutic use in medicine.

- One subset of these drugs is biochemicals, which are drugs of plants and animal origin (as opposed to mineral), whether derived from natural products or by means of laboratory synthesis. Biochemicals range in complexity from simple organic buffers to complex products of metabolism such as vitamin B_{12}.

- Immunochemicals are a subset of biochemicals. They include antisera and antigens, which are used to provide immunity to diseases or to control the advance of maladies or of abnormal bodily functions.

A breakdown of the latter two types into major categories is shown in Figure 9-1. Each of the categories on the bottom tier of the chart represents from tens to hundreds of individual chemical compounds.

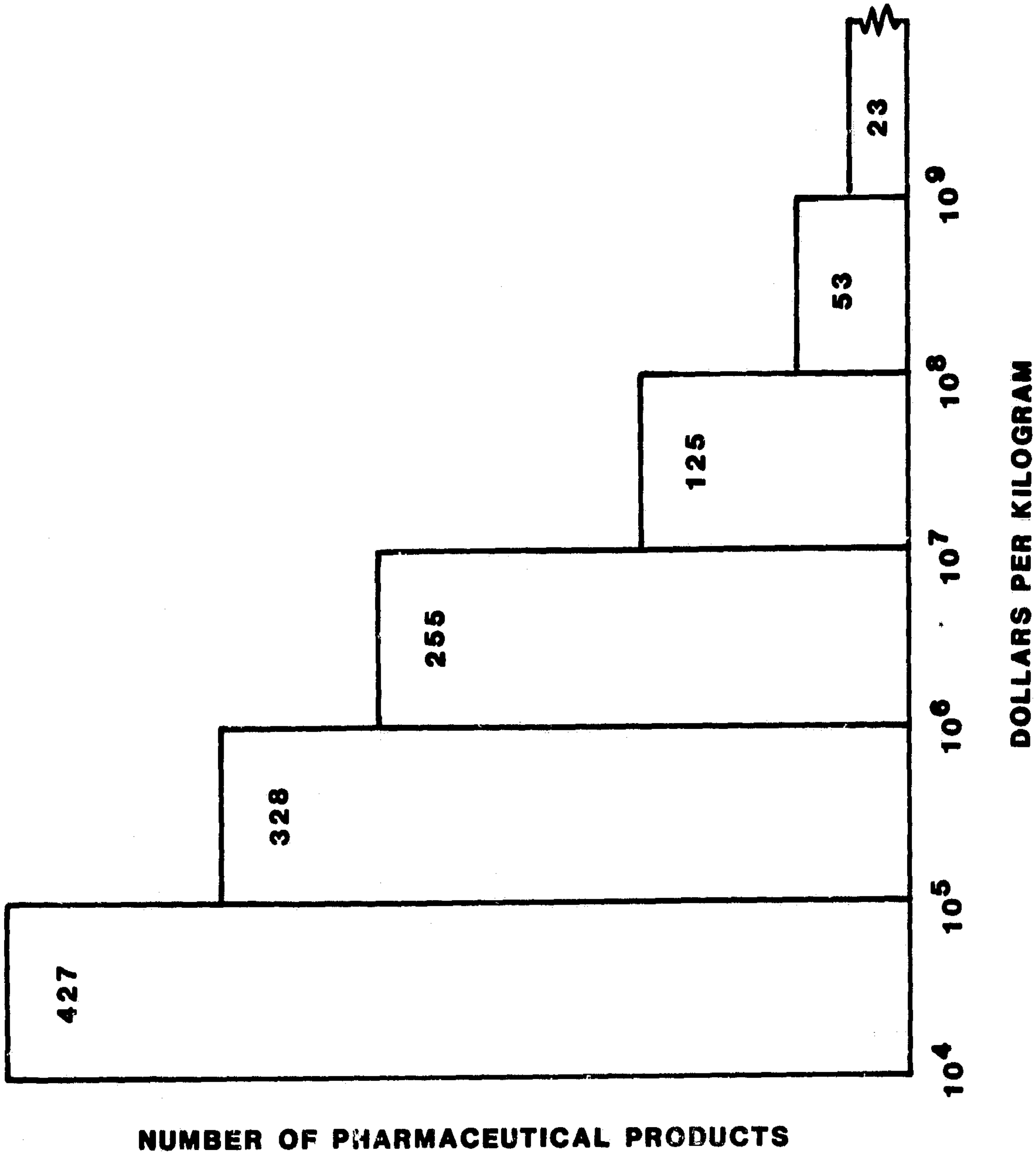
Drugs constitute the most conspicuous category of materials exhibiting the property of high value to weight ratio.

Table 9-1 illustrates a sample of drugs that retail for more than $1,000,000,000 per kilogram. Figure 9-2, constructed from a drug specialty catalog, depicts the distribution of numbers of drug types as a function of price.

TABLE 9-1

SELECTED PHARMACEUTICALS SOLD FOR MORE THAN
ONE BILLION DOLLARS PER KILOGRAM

Pharmaceutical	Billion Dollars Per Kilogram
Alfatoxin M_1, Aspergillus flavus	$ 5.00
Bothropsinase Reagent	14.50
Cholecystokinin Octapeptide	1.80
Chorionic Gonadotropin, (hCG), Human, Iodination grade	3.20
Chymotrypsin, Human Pancreatic, Iodination grade	3.00
C-Peptide, Human, standard	1.80
C-Peptide, Human, Tyrosylated, Iodination grade	8.00
Deoxyribonucleic Acid, SV40	6.25
Ferritin, Human, Spleen, Iodination and standard grade	2.45
α- Feto Protein (AFP), Human, Iodination grade	2.50
α- Feto Protein (AFP), Human	20.00
α- Feto Protein (AFP), Mouse	1.50
Follicle-Stimulating Hormone, (hFSH), Human, Iodination grade	5.60
Growth Hormone, Human (hGH), Iodination grade	2.00
Luteinizing Hormone, Human (hLH), Iodination grade	2.15
Parathyroid Hormone, (PTH), Bovine 1-84, Iodination grade	5.00
Prolactin, Human (hPRL), Iodination grade	2.45
Thyroid-Stimulating Hormone, Human, Pituitary (hTSH), Iodination grade	4.00
Thyroid-Stimulating Hormone, Human, α- subunit, (hTSH), Iodination grade	5.30
Thyroid Stimulating Hormone, Human, β- subunit, (hTSH), Iodination grade	4.36
Trypsin, Human, Pancreas, Iodination grade	3.00
Vinculin, Chicken Gizzard	1.00



* 1983 BIOCHEMICAL AND IMMUNOCHEMICAL CATALOG/HOECHST

Figure 9-2. Representative Costs of Selected Pharmaceuticals*

There is a continuing need in the biomedical community for improved separation and purification techniques for specific products related to cell components, cell byproducts and proteins.

Efficient separation is required because these materials are found in very low concentrations, and are found embedded in matrices of other very similar materials, e.g., beta cells in a mixture of cells comprising a pancreas. The process of achieving these materials in concentrated form is thus quite costly.

Purification is important in many cases where the desired, or target drug, can be found in its original form intermixed with substances which are either potentially harmful, or which produce undesired side-effects. High priority candidates for separation and purification in the space environment are beta cells, interferon, epidermal growth factor products, growth hormone products, antitrypsin products and antihemophilic products.

Electrophoresis in microgravity has demonstrated the distinct promise of improved separation and purification. Improved separation is tantamount to higher throughput. Better purification leads to higher-resolution separation between the target material and its background. McDonnel Douglas estimates that electrophoretic processing in space can enhance throughput by a factor of perhaps 500, with up to a five-fold increase in purity over earth-bound processes.

9.2.2 LARGE MONODISPERSED LATEX SPHERES

It was found quite by accident several years ago that a polyvinyl latex, grown by polymerization of a monomer in the presence of a surfactant and water, yielded a vast number of microscopic spherical particles that were nearly identical in size. The size distribution was so narrow that the particles became widely used as calibration standards for electron microscopy. In a short time, a remarkable number of uses was found for these monodispersed particles, ranging from seriological tests for a number of diseases to measuring pore sizes in biological and other membranes.

During the conventional terrestrial growth process, the latex spheres are maintained in suspension by intrinsic Brownian motion until their diameter reaches approximately two microns, at which point they tend to sediment under normal one-g gravity.

For larger diameters, the sphere's suspension can be further maintained by gentle stirring; however, extreme care must be taken to prevent flocculation or the initiation of a new batch of particles. For this reason, monodispersed spheres are not commercially available in large sizes. MPS literature identifies the breakover point as occurring at 2 microns, but MSFC researchers communicate that the Dow Chemical Company has recently placed on the market spheres as large as 10-15 microns.

MSFC has developed a unique process which has demonstrated the production of spheres up to 40 microns in diameter, with characteristics of uniformity of diameters and deviation from roundness considerably superior to those achieved commercially. This MSFC process has been tested on the ground. MSFC researchers estimate that significantly improved characteristics of uniformity of diameters, roundness, and diameter upper dimensions, are achievable by microgravity processing.

Ground-produced spheres up to 15 microns in diameter are sold currently in one ounce bottles containing 0.1% solid spheres for $65. This equates to $473,000 per kilogram at retail price. It is believed that larger sizes, up to 40 microns, will command a higher price. MSFC estimates that space production costs for latex spheres will range from $900 per gram for 50 kilograms produced to $500 per gram for 200 kilograms produced annually*.

9.2.3 "ULTRA-SOFT" MAGNETIC MATERIALS

The operation of transformers, motors, generators, magnetic memories and other devices which operate with alternating or variable currents and which utilize materials conventionally designated "ferromagnetic" is less than completely efficient in terms of energy transformed versus energy lost. The two primary sources of energy losses are those associated with hysteresis and eddy currents. Losses are caused by heat generated by these effects in the presence of alternating or variable currents.

---

* Op cit briefing to NASA Headquarters

Eddy current losses are proportional to the square of the frequency of the alternating current. They can be controlled to some extent by the geometry of the ferromagnetic elements employed in these devices. Hysteresis losses are a function of the frequency and are dominated by the choice of ferromagnetic materials.

Hysteresis is the phenomenon whereby the magnetization of ferromagnetic materials (expressed as the flux density, B) "lags" behind the action of the field (expressed as the magnetic field strength, H). When, in the process of reversing the magnetic field, the magnetic field strength is decreased to zero, the flux density retains some residual value -- termed remanence, residual induction or retentivity.* Conversely, a certain amount of opposite-polarity magnetic field strength is required to cancel out the retentivity. This is known as the coercive force. The integral under the retentivity-coercive force loop is proportional to the hysteresis loss. Hence, the "softer" the magnetic properties of a ferromagnetic material, the smaller the hysteresis loss and correspondingly the greater the energy efficiency of the device.

An important category of MPS experimentation addressed the production of bulk metallic glasses. The object of this experimentation was to explore the feasibility of containerless processes to produce metallic glasses by severe undercooling while eliminating container-induced nucleation sites. Manufacture of small amounts of metallic glass in ground-based research has resulted in the unexpected observation that the Pd-Si-Cu compound selected for experimentation exhibited "very soft" magnetic properties. Thus far, (SPAR) flight experiments have failed due to equipment failure, but work continues to refine the experiments protocol.

Currently, metallic glasses may be made on earth in very small quantities due to limitations in the technology for rapidly cooling such glasses to the

---

* Permanent (so called "hand") magnets characteristically have high remanence while "soft magnets" are ferromagnetic materials with low remanences.

amorphous state, bypassing crystallization. MPS technology portends the possibility of learning to produce macroscale amounts from which to fabricate high-grade high-frequency laminations or ferrite-like transformer cores.

9.2.4 IMMISCIBLE MATERIALS

Immiscible materials represent a broad category of multiphase material systems which exhibit a "miscibility gap" in their phase diagram. That is to say, that at a particular relative concentration one component of the system tends to separate from the other and the two materials cannot be mixed. One classic example is oil and water. Certain metal alloys cannot be made readily because the metals separate when melted and continue to remain distinct upon cooling. Several materials of interest for space processing involve fluid phases, where the effect of gravity on processing could be pronounced.

From theoretical investigations*, a number of compounds have been identified which might exhibit properties of:

- superconductors,
- electrical contact materials,
- III - V semiconductors,
- catalysts,
- permanent magnets,
- bearings, and
- superplastic materials,

and whose components are immiscible in a fluid phase. For example, nearly 250 materials have been identifed as potential superconductors (see Table 9-2).

Skylab experimentation investigated the possibility of preparing immiscible alloys by isothermal and directional solidification. One alloy, 76.85 weight percent gold and 23.15 percent germanium, was selected for test because it exhibits almost complete solid state immiscibility. As expected, samples

---
* See Gelles, S.H. Et. Al. 1977. Referenced in Bibliography.

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 9-2

SYSTEMS OF LIQUID PHASE IMMISCIBLE MATERIALS
SUGGESTED FOR SUPERCONDUCTING PROPERTIES

Ag-Cb	B-Bi	Bi-Ru	Cb-Pb	Cr-Sn	Ga-Hg	La-Ta	Mo-Sb	Pu-Ta
Ag-Ir	B-Cd	Bi-Si	Cb-Pu	Cs-Ga	Ga-K	La-Ti	Mo-Sc	Re-Sn
Ag-Mo	B-Ga	Bi-U	Cb-Sc	Cs-In	Ga-Pb	La-U	Mo-Sn	Re-Zn
Ag-Re	B-Hg	Bi-V	Cb-Sn	Cu-Mo	Ga-Te	La-V	Mo-Y	Ru-Zn
Ag-Ru	B-In	Bi-W	Cb-Y	Cu-Os	Ga-Tl	La-Yb	Na-Ta	S-Sn
Ag-Ta	B-Pb	Bi-Zn	Cb-Yb	Cu-Pb	Ga-W	La-Zr	Na-U	S-Tl
Ag-U	B-Sn	C-Cd	Cd-Cr	Cu-Re	Gd-Mo	Li-Mo	Na-Zn	Sc-U
Ag-V	B-Tl	C-Hg	Cd-Fe	Cu-Ru	Gd-Ta	Li-Ta	Na-Zr	Sc-V
Al-As	Be-Bi	C-Pb	Cd-Ga	Cu-Ta	Gd-U	Li-Ti	Nd-Ta	Se-Sn
Al-Bi	Be-Ga	C-Sn	Cd-K	Cu-Tl	Gd-V	Li-U	Nd-Ti	Se-Tl
Al-C	Be-Ge	C-Tl	Cd-Pu	Cu-U	Gd-W	Li-V	Nd-U	Se-Zn
Al-Cd	Be-Hg	C-Zn	Cd-Se	Cu-V	Ge-Hg	Li-Zr	Nd-V	Si-Tl
Al-Cs	Be-In	Ca-Cb	Cd-Si	Dy-Mo	Hg-Sc	Lu-Ta	Ni-Pb	Sm-U
Al-In	Be-Mg	Ca-Cd	Cd-Tc	Dy-Ta	Hg-Si	Lu-U	Os-Sn	Sm-V
Al-K	Be-Pu	Ca-Gd	Ce-Mo	Dy-Ti	Hg-Ta	Lu-V	P-Sn	Sm-W
Al-Na	Be-Sn	Ca-La	Ce-Ta	Dy-U	Hg-V	Mg-Mo	P-Tl	Ta-Tb
Al-Pb	Be-U	Ca-U	Ce-Ti	Dy-V	Hg-W	Mg-Ti	Pb-Pm	Ta-Y
Al-Rb	Bi-C	Cb-Ce	Ce-U	Er-Mo	Ho-U	Mg-U	Pb-Se	Tb-U
Al-S	Bi-Cb	Cb-Cu	Ce-V	Er-Ta	In-S	Mg-V	Pb-Si	Te-Tl
Al-Tl	Bi-Co	Cb-Er	Ce-Zr	Er-Ti	In-Se	Mg-Zr	Pb-U	Th-U
As-Hg	Bi-Cr	Cb-Gd	Co-Hg	Er-U	In-Te	Mn-Pb	Pb-W	Th-Yb
As-Tl	Bi-Pe	Cb-K	Co-Pb	Er-V	K-Mo	Mn-Tl	Pb-Zn	Tl-Zn
Au-Ir	Bi-Ga	Cb-La	Co-Tl	Eu-U	K-Zn	Mo-Nd	Po-Ta	Tm-U
Au-Os	Bi-Ge	Cb-Li	Cr-Gd	Fe-Hg	La-Mn	Mo-Pb	Pr-Ta	U-Y
Au-Re	Bi-Mn	Cb-Mg	Cr-Hg	Fe-Pb	La-Mo	Mo-Po	Pr-Ti	U-Yb
Au-Rh	Bi-Mo	Cb-Na	Cr-Ta	Fe-Sn	La-Pu	Mo-Pr	Pr-U	U-Zn
Au-Ru	Bi-Os	Cb-Nd	Cr-Pb	Fe-Tl	La-Re	Mo-Pu	Pr-V	V-Y
								V-Yb
								W-Zn

solidified in space were significantly more homogeneous in structure than their counterparts produced on earth. The space-produced samples exhibited superconductivity at 1.5oK, which ground-manufactured samples did not.

This suggests the value of processing a large number of materials such as shown in Table 9-2 for futher research on earth, whether the final result is either a better understanding of earth-bound technology or identification of products of sufficiently unique and valuable characteristics to warrant manufacture in space.

9.2.5 HIGH-STRENGTH MATERIALS

The object of this subsection is to exemplify the ultimate potential obtainable in the technology of materials processing. The specific example selected pertains to the stress-strain characteristics of materials.

A limited number of MPS investigations has shown instances where microgravity processing has yielded tensile strengths up to 50% greater than obtained from the same materials processed under terrestrial gravity. Past investigations leading to the above-stated results were interfered with by sundry inadequacies and misfunctionings of the experimental equipment. This may have possibly interfered with the production of even higher-strength materials. Nevertheless, the promise of achieving materials with above-normal stress-strain characteristics has definitely emerged.

Table 9-3 shows the tensile strengths of materials commonly used in industry for purposes of civil building, machine construction, and applications requiring high structural performance.

Note that the class of materials, represented in Table 9-3 by boron, and generally included within the broad designation of "ceramics", exhibits tensile strengths which are approximately four to five times that of high-strength steel.

TABLE 9-3

TENSILE STRENGTH OF SELECTED MATERIALS

MATERIAL	TENSILE STRENGTH KG/CM^2
IRON FOR CONCRETE REINFORCEMENT	4,000
STRUCTURAL STEEL	10,000
HIGH-STRENGTH STEEL	22,000
DURALUMINUM	4,500
BORON	99,000

The problem with these materials is that they are brittle as well as strong. Brittleness connotes the property of propensity to cracking. Microfractures in ceramics, once started, tend to propagate and enlarge, until the high strength which is characteristic of the pristine material dwindles and crumbles.

This is why, aside from cost considerations, we do not use structural beams fashioned from boron. While initially immensely strong, a few hammer blows would be sufficient to induce cracking, and soon thereafter the fracturing of the beam.

Modern materials technology has succeeded in exploiting the tensile strength characteristics of ceramic materials by the technique commonly labeled "embedded fiber technology." Small-diameter fibers of boron, for example, are embedded in a matrix of a softer material--e.g., aluminum, copper. The boron fibers provide the tensile strength, the metal matrix insures protection from cracking.

An even more exciting vista of ultra-strong materials is afforded by the theoretical consideration of the binding forces which underlie the cohesion of matter.

As is well known, the principal intermolecular forces in such a structure are of two kinds: the binding-force attraction between charges of opposite electrical polarity, and the strong quantum repulsion caused by the physical proximity between material particles. The existence of simple material structures is commonly regarded as resulting from the equilibrium of these two opposing forces.

Table 9-4 illustrates the ideal case of a material structure of the ionic type (ionic crystal), subject to the coulomb attraction between mono-ionic molecules neglecting the repulsive force caused by the strong quantum interaction (which varies with an exponential law of their distance.)

The "Mabelungen factor", indicated in Table 9-3, expresses the integration of the attractive forces between ions of opposite signs with the repulsive forces between homeopolar ionic charges. Note that the ultimate theoretical strength of

TABLE 9-4

SUPER-STRENGTH MATERIALS II

INTERMOLECULAR IONIC
BINDING FORCE-IDEAL CASE

$$T = \frac{Q^2 \times 10^{-4}}{4 \pi \varepsilon \ R^4 M}$$

T = IDEAL TENSILE STRENGTH, Kg/CM^2

Q = ELECTRON CHARGE = 1.6×10^{-19} COULOMB

ε = DIELECTRIC CONSTANT = 8.84×10^{-12} FARAD/METER

R = INTERMOLECULAR DISTANCE, METERS

M = MABELUNGEN FACTOR

SOLVE FOR BORON CRYSTAL

T = 2,000,000 KG/CM^2

an ionic material appears to be of order twenty times that of conventionally produced materials.

9.3 CONCLUSION

In each of the five examples just discussed, a product of known or potential value was identified:

Pharmaceuticals: Beta Cells, Interferon, Epidermal Growth Factor, etc.

Large Monodispersed Latex Spheres: The spheres themselves

High Strength Materials: Composites such as SiC/Ag

Ultra-Soft Magnetic Materials: Ferromagnetic parts for high frequency electronic devices

Immiscible Materials: Superconductors

More complete identification will be pursued during the next phase of this effort.

X - INDUSTRY SURVEY FINDINGS

10.0 DIRECT QUERY PROGRAM

The goal of the direct query program was to ascertain the interest in MPS on the part of U.S. industry, and the potential obstacles, real or perceived, to industry's participation in the MPS program.

In support of this goal, the principal objectives of the direct query program were to:

- Assess the best potential candidates for MPS among the products produced and processes employed by selected industries;
- Determine the readiness of industries to enter into some form of participation in the MPS program;
- Assess the key drivers which motivate or deter industry to participate with NASA in MPS activities;
- Assist in the structuring of a logical program for NASA-industry cooperation in MPS, which responds to industrial requirements.

The direct query program was conducted through interviews with key personnel of selected industries. The persons interviewed were advised that their responses would be kept confidential, i.e., not given general dissemination. After permission was granted, the raw data derived from these interviews were distributed to selected NASA officials.

The industries and personnel interviewed are coded alphabetically in the presentation of the survey results which follows.

10.1 CRITERIA FOR SELECTING INDUSTRIES TO BE QUERIED

Two limiting approaches were available for selecting respondent industries:

- The follow-up approach, i.e., contacting industries known to have already been exposed to MPS concepts, techniques and technologies;

- The sample approach, i.e., contacting industries substantially on a stratified random basis.

Since the intent of this effort was to obtain the widest possible sample of attitudes from U.S. industry, and NASA was already engaged in follow-up activities with several industries, the follow-up approach was rejected in favor of the sampling method.

Initial sampling criteria were established as follows, to focus on plausible candidates

- Non-overlap criterion. MPS customers currently negotiating with NASA were not sampled.

Thus, aerospace industries were excluded from the sample, as well as the Space Station definition endeavor, and a significant portion of very large companies.

- The stratification criterion. Potential respondents were limited to representatives from those industries which are currently engaged in activities most germane to MPS.

The following sub-criteria delimit the stratification criterion:

- Industries whose products sell for a significant price per unit weight;

- Industries who engage in high technology processes;

- Industries whose products sell for relatively low prices but in such large quantities and through processes of sufficiently high technology that even minor improvements in processing could result in significant economic advantages;

- Industries whose products and/or processes bear a strong analogy to the products/processes already experimented within NASA's MPS program.

From these sub-criteria, industries such as mining and quarrying (Standard Industrial Classification B-14), and Agricultural/Production - crops (SIC A-01) were eliminated. In fact, a large portion of the SIC categories defined by OMB were eliminated. It should, however, be noted that such actions should not be considered as final, but only as an initial means to focus quickly upon what appeared to be the most promising industries. It is in fact entirely possible that subsequent in-depth analyses of the "eliminated" industries may reveal unsuspected applications of interest to MPS.

By applying the above criteria, the following industries were given a most promising status from the outset:

- Medium size industries which specialize in the research, manufacture and development of pharmaceuticals, high value chemicals and highly technical expensive industrial equipment;

- Industries which produce technological materials selling at low cost, but in such large quantities that minor improvements in processing would lead to significant increases in sales and profits. An example of this category is the aluminum industry.

10.2 INFORMATION SOUGHT AND GLEANED FROM DIRECT QUERIES

Queries to potential customers were based on a hierarchy of meaningful information expectations relating to MPS objectives. A summary of the information sought from possible MPS users is presented in Table 10-1.

Respondents were not expected to address each of the items, per se, that appear in the Table. Rather, information was elicited in an open dialogue, with the interviewer assuming primarily a listening role.

The basic intent of the information sought and its relationship to the program's objectives should be apparent from a review of the Table. It may nevertheless be useful to address its principal features. The information sought falls into 4 categories.

TABLE 10-1

INFORMATION SOUGHT FROM POTENTIAL MPS USERS

1. PROFILE OF COMPANY

   - Annual Sales, Profitability, Areas of Business Endeavor, Areas of Research
   - Normal planning horizon
   - Responsibility of discussant within the company

2. PLANNING FUNCTION.

   - Who in the company, if anyone, is responsible for maintaining awareness of broad business opportunities
   - If no one, how is planning accomplished.
   - If yes, which areas have priority. How are priorities established. How is their "priority rank" measured or assessed.
   - Is space opportunity included. Where does it fit.

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT

   - Has the Company heard of space opportunities. If so, to what extent, how, from whom

   If space opportunities are not included in current planning, is this because:

   - They were never considered
   - They were considered and discarded after limited analysis
   - They were considered and rejected after mature analysis
   - What were the factors that led to the discard decision

4. FUTURE INTEREST

   - Will company seek out space opportunities on their own
   - Should such opportunities be offered to them
   - Who should take the next step: the company or NASA
   - What should be the next step

- The first category covers the general business environment and performance of the industry, its principal products and R&D endeavors. This information provides an initial "fix" as to which categories of products, or which type of R&D, emerge as MPS--addressable among the queried industry's activities.

  Very important is the time span of the particular industry's planning horizon: this serves to calibrate the "tempo", from initiation to fruition of a new endeavor, within which the respondent industry must normally react.

  The question of the discussant's responsibility confirmed whether the selection of the respondent -- carefully performed prior to the interview-- did indeed fall upon an individual who could authoritatively speak to the company's interest, or would lead or commit the company to MPS--oriented endeavors.

- The second category explores how the respondent industry performs its planning, and, in particular, whether space-oriented opportunities are included in its planning functions.

- The third category is designed to assess whether there is a need on NASA's part for expanded "industry awareness" efforts; and, if such awareness exists, the motivators for acceptance or rejection of space opportunities in the respondent's planning process.

- The fourth category addresses the key questions, "what does it take to interest you in space" and "where do we go from here."

The information elicited from the direct queries is summarized in Tables 10-2 through 10-6. Its significance is discussed following.

TABLE 10-2

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		A
RESPONDENT CODE:		A-1
1.	PROFILE OF COMPANY	
1.1	Annual sales, $Million, 1982	4,3000
1.2	Overall Profit margin, pre tax, %	
1.3	Ratio of R&D expeditures to sales %	
1.4	Principal Products addressable by MPS	Pharmaceuticals except blood products
1.5	Sales Volume of the MPS-addressable Products, $ Million	1,100
1.6	Principal Areas of MPS-addressable R&D	Pharmaceuticals
1.7	Planning horizon for bi-tech products, years	2 to 3
1.8	Responsibility of discussant	Planning of new hi-tech products, direction of R&D
2.	PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES	
2.1	Who is responsible for planning	Respondent A-1

TABLE 10-2 (continued)

	2.2	If no one, how is planning accomplished	N.A.
	2.3	Which areas have priority	Those for which market is most favorable in terms of future profits
	2.4	How are priorities established	In terms of profitability
	2.5	How are priorities ranked and measured	In terms of profitability
	2.6	Is space opportunity included	Not included
	2.7	If so, in what area, product, or process	N.A.
3.	AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)		
	3.1	Has Company heard of MPS opportunities	Yes
	3.2	To what extent	General knowledge
	3.3	How and from whom	Scientific/Technical literature
	3.4	If not, why	N.A.
4.	IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING		
	4.1	To what extent were they considered	To a limited degree
	4.2	Were they considered and discarded after limited analysis	Yes

TABLE 10-2 (continued)

4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	Limited "thinking" time on the part of senior planners and scientists
5.	**HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES**	
5.1	On their own	No
5.2	After opportunities are offered	Yes, if promising
5.3	In what form should opportunities be presented	Not necessary to propose specifics. Stimulating results/examples are sufficient
6.	**THE NEXT STEP**	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	Discussion with top-level NASA representatives
6.4	Will the Company consider further steps, or a programmatic approach	Yes. Presentation of opportunities to planners/scientists

TABLE 10-3

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		B
RESPONDENT CODE:		B-1
1.	PROFILE OF COMPANY	
1.1	Annual sales, $ Million, 1982	1,114
1.2	Overall Profit margin, pre-tax, %	13
1.3	Ratio of R&D expeditures to sales %	4.5
1.4	Principal Products addressable by MPS	Medication delivery systems, Laboratory diagnostic equipment
1.5	Sales Volume of the MPS—addressable Products, $ Million	300
1.6	Principal Areas of MPS—addressable R&D	
1.7	Planning horizon, for hi-tech products, R&D2	
1.8	Responsibility of discussant	Planning improvements and innovations of Company's medical products
2.	PLANNING FUNCTION FOR MPS-CANDIDATE PRODUCTS AND PROCESSES	
2.1	Who is responsible for planning	Respondent B-1, together with Marketing Departments

TABLE 10-3 (continued)

2.2	If no one, how is planning accomplished	N.A.
2.3	Which areas have priority	Those which promise most profitability
2.4	How are priorities established	Based on market forecasts
2.5	How are priorities ranked and measured	Based on market forecasts
2.6	Is space opportunity included	No
2.7	If so, in what area, product, or process	N.A.
3.	AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)	
3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Broad general knowledge
3.3	How and from whom	Scientific/technical literature/contacts with Mr. Mogavero
3.4	If not , why	N.A.
4.	IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING	
4.1	To what extent were they considered	To a very limited degree
4.2	Were they considered and discarded after limited analysis	Yes

TABLE 10-3 (continued)

4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	Limited "thinking" time on the part of senior planners and scientists
5.	HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES	
5.1	On their own	No
5.2	After opportunities are offered	Probably, if promising
5.3	In what form should opportunities be presented	Not necessary to propose specifics Stimulating results/examples are sufficient
6.	THE NEXT STEP	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	Presentation of opportunities to planners/marketeers/scientists
6.4	Will the Company consider further steps, or a programmatic approach to space opportunities	Not defined at this time

TABLE 10-4

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:	C
RESPONDENT CODE:	C-1
1. PROFILE OF COMPANY	
1.1 Annual sales, $ Million, 1982	6,130
1.2 Overall Profit margin, pre-tax, %	8
1.3 Ratio of R&D expeditures to sales, %	1
1.4 Principal Products addressable By MPS	Chemical Specialties, including catalysts
1.5 Sales Volume of the MPS--addressable Products, $ Million	2,000
1.6 Principal Areas of MPS--addressable R&D	Basic Chemical R&D, Chemical R&D
1.7 Planning horizon, for hi-tech products, years	2-3
1.8 Responsibility of discussant	Planning of New Business Ventures. Planning, directing, implementing R&D.
2. PLANNING FUNCTION FOR MPS--CANDIDATE PRODUCTS AND PROCESSES	
2.1 Who is responsible for planning	Respondent C-1
2.2 If no one, how is planning accomplished	N.A.

TABLE 10-4 (continued)

2.3	Which areas have priority	Those where product profitability promises to be highest
2.4	How are priorities established	Market forecasts
2.5	How are priorities ranked and measured	Based on market forecasts
2.6	Is space opportunity included	No
2.7	If so, in what area, product, or process	N.A.
3.	AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)	
3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Broad general information
3.3	How and from whom	Scientific/Technical literature
3.4	If not, why	N.A.
4.	IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING	
4.1	Were they considered and discarded after limited analysis	Yes
4.2	Were they considered and rejected after mature analysis	No
4.3	What were the factors that led to the discard decision	Apriori assumption that MPS is just Public Relations without substance

TABLE 10-4 (continued)

5.	HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES	
5.1	On their own	No
5.2	After opportunities are offered	Yes, if worthwhile
5.3	In what form should opportunities be presented	Specifics if possible. Stimulating analogies from results achieved within the Company product line would be considered
6.	THE NEXT STEP	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	Discussion with high-level NASA technology representative
6.4	Will the Company consider further steps, or a programmatic approach to space opportunities	Possibly, if intial steps portend availability of worthwhile prospects for products and/or processes.

TABLE 10-5

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:	D
RESPONDENT CODE:	D-1
1. PROFILE OF COMPANY	
1.1 Annual sales, $ Million, 1982	
1.2 Overall Profit margin, pre-tax, %	
1.3 Ratio of R&D expeditures to sales, %	
1.4 Principal Products addressable by MPS	Aluminum sheet products Aluminum forgings and castings
1.5 Sales Volume of the MPS--addressable Products, $ Million	
1.6 Principal Areas of MPS--addressable R&D	Large scale aluminum refining, rolling, casting, forging
1.7 Planning horizon, for hi-tech products, years	1-2
1.8 Responsibility of discussant	Director of Research
2. PLANNING FUNCTION FOR MPS--CANDIDATE PRODUCTS AND PROCESSES	
2.1 Who is responsible for planning	Respondent D-1
2.2 If no one, how is planning accomplished	N.A.

C-2

TABLE 10-5 (continued)

2.3	Which areas have priority	Those where product profitability promises to be highest
2.4	How are priorities established	Market forecasts
2.5	How are priorities ranked and measured	Based on market forecasts
2.6	Is space opportunity included	No
2.7	If so, in what area, product, or process	N.A.
. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)		
3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Broad general information
3.3	How and from whom	Scientific/Technical literature and prior calls by NASA or NASA contractor personnel
3.4	If not , why	N.A.
IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING		
4.1	Were they considered and discarded after limited analysis	Not considered
4.2	Were they considered and rejected after mature analysis	No
4.3	What were the factors that led to the discard decision	Apriori assumption that MPS cannot contribute to improving low-cost products

TABLE 10-5 (continued)

5.	HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES	
5.1	On their own	No
5.2	After opportunities are offered	Yes, if worthwhile
5.3	In what form should opportunities be presented	Specifics as much as possible. Show that there is a logical rationale towards generation of commercially viable product.
6.	THE NEXT STEP	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	Focused discussion with high-level NASA technology representative
6.4	Will the Company consider further steps, or a programmatic approach to space opportunities	Possibly, if intial steps portend availability of worthwhile prospects for ultimately producing economically viable product.

TABLE 10-6

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		E
RESPONDENT CODE:		E-1
1.	PROFILE OF COMPANY	
1.1	Annual sales, $ Million, 1982	Not publicly releasable
1.2	Overall Profit margin, pre-tax, %	Not publicly releasable
1.3	Ratio of R&D expeditures to sales, %	Not publicly releasable
1.4	Principal Products addressable By MPS	High technology, brass and aluminum castings
1.5	Sales Volume of the MPS--addressable Products, $ Million	Not publicly releasable
1.6	Principal Areas of MPS--addressable R&D	High precision machineless spherical castings
1.7	Planning horizon, for hi-tech products, years	1-2
1.8	Responsibility of discussant	Planning of new products, direction of R&D
2.	PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES	
2.1	Who is responsible for planning	Respondent E-1
2.2	If no one, how is planning accomplished	N.A.

TABLE 10-6 (continued)

2.3	Which areas have priority	Those for which market is most favorable in terms of future profits
2.4	How are priorities established	In terms of profitability
2.5	How are priorities ranked and measured	In terms of profitability
2.6	Is space opportunity included	Not included
2.7	If so, in what area, product, or process	N.A.
3.	**AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)**	
3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Limited knowledge
3.3	How and from whom	Scientific/Technical literature
3.4	If not , why	N.A.
4.	**IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING**	
4.1	To what extent were they considered	Not considered
4.2	Were they considered and discarded after limited analysis	N.A.
4.3	Were they considered and rejected after mature analysis	
4.4	What were the factors that led to the discard decision	N.A.

TABLE 10-6 (continued)

5.	HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES	
5.1	On their own	No
5.2	After opportunities are offered	Yes, if worthwhile
5.3	In what form should opportunities be presented	Propose specifics
6.	THE NEXT STEP	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	Focused discussion with top-level NASA representatives
6.4	Will the Company consider further steps, or a programmatic approach	Yes, by presenting opportunities to management

10.3 FINDINGS

Several key personnel characteristics, common to all respondents, can be deduced from the visits to potential constituent industries:

- The individuals representing high level technical, decision-making and new venture management are well versed in scientific matters.
- There is considerable knowledge and interest in the space effort among this high level management. However, it has little time available to explore the potential offered by the space program.
- High-level management is pressed to produce new technologies related to its products.
- It welcomes being apprised of new technological potentials, including the space potential.
- Application of the space potential should be focused on mangement's specific product/process/problem areas.
- Management would be willing to invest resources, (e.g., funds, skilled personnel) if real possibilities for tangible development could be perceived.

The net conclusion from these factors is a realization that NASA, if it is to foster the growth of space commercialization, must devote a concerted effort to clarifying the issues evident from the summary above. This will require an orchestrated effort to work with potential constituent industries, on such issues as the most promising areas of technological innovation in their particular problem areas, the potential application of space technology for these problem areas, and the developing of new forms of experimentation. Potential constituents should be led into an involvement with the space commercialization effort in an orderly, well thought out manner. It is not sufficient to make presentations on the various space programs, e.g., STS or the availability of experimental facilities. The potential candidate industries should be fully apprised of all scientific and engineering possibilities, the interest of NASA in trying to solve their problems, and NASA's willingness to work with them to establish sound experimental curricula tailored to their interests. A few visits and a symposium or two will not induce

industries to utilize the available NASA facilities, including STS flights. This need for an organized presentation is most critical when potential constituent industries are approached to participate in the Space Commercialization Program.

XI - CONCLUSIONS AND RECOMMENDATIONS

11.0 GENERAL

The results of the Task I effort of the "User Requirements for the Commercialization of Space" Contract were, as expected, preliminary in nature. More work will ultimately be needed to generate a visible plan for the development of a broad constituency for space commercialization.

General difficulties in elucidating a concise set of expectations for the MPS Program, and questions relating to the proper categorization of its results suggested the necesity for more extensive efforts to obtain data and information that was originally planned. In addition, more analysis was required to summarize the value and potential of space experimentation within the context of industrial product development.

Several conclusions and recommendations, however, may be generated from Task I. They are presented below.

11.1 CONCLUSIONS

The Task I effort resulted in the following conclusions:

- Principal Investigator and Contractor Reports were the most useful methods for determining the current status of space commercialization experimentation. These documents, however, are difficult to obtain and not readily accessible from a centralized depository.

- The experimental results were couched in technical terminology relating to the experimentation and required careful analysis to ascertain the potential for commercialization.

- The majority of MPS experimental results to date are still in the research stage of development.

- The electrophoresis of pharmaceuticals and manufacture of monodispersed latex spheres have current commercialization potential. In addition, ultra strong materials, "soft" magnets and immersible alloys appeared to offer promise for commercialization.

- A number of useful apparatus have been developed for use in space experimentation.

- Industrial R&D managers were interested in space commercialization and willing to listen to promising concepts.

- Time constraints, however, limited their capacity to think out the uses of space. As a results, they requested more research into their own particular areas of technological interest.

- They would be willing to devote resources, in terms of personnel and money, towards improvements in space commercialization if they could perceive real possibilities for its economical and efficient application.

11.2 RECOMMENDATIONS

The preliminary recommendations resulting from Task I were:

- A centralized data source for MPS Program results be established for ready and quick reference by interested parties;

- The MPS Program results be translated into coherent terminology for potential use by industrial organizations;

- All space commercialization apparatus be clearly identified and then commercial applications be postulated;

- An organized space commercialization agenda be developed by NASA for presentation to industry. It should embody a careful build-up process for attracting industries, and assure continued NASA attention to potential user's needs.

11.3 SUGGESTED CONSTITUENCY BUILD-UP PROCESS

It is recommended that NASA develop a well thought out process for attracting industries and fostering their involvement in the Space Commercialization Program. Figure 11-1 is a schematic of how such a process could conceivably work. It is comprised of the following steps:

1. Expose to Potential - This is accomplished through a variety of activities. For instance, the on-going efforts by the Office of Technology Utilization and Industry Affairs are performed on a one-to-one basis, using a technical presentation summarizing past space experimentation accomplishments and focusing on potential areas of application relative to the interests of constituent industries. Additional constituents may result from contacts made by other NASA offices such as STS, OSA; and, from focused technical meetings and other exchanges.

2. Explore Interest - Once potential constituent industries are identified, and some interest or willingness to talk further are evidenced, a follow-up program should be pursued. Its intent, of course, is to further nurture the initial interest. At this stage, every effort should be made to understand the industry concerned, and to address its problem areas from both a technical and economic point of view. An informal agreement for further cooperation should be solidified.

   The assignment of a Case Officer or liaison personnel might be instrumental in bringing this and subsequent steps to a successful completion. Candidate industries would have access to specific contacts within NASA; meaningful exchanges between NASA and management would, presumably, be enhanced.

COMMERCIALIZATION CONSTITUENCY BUILD-UP PROCESS

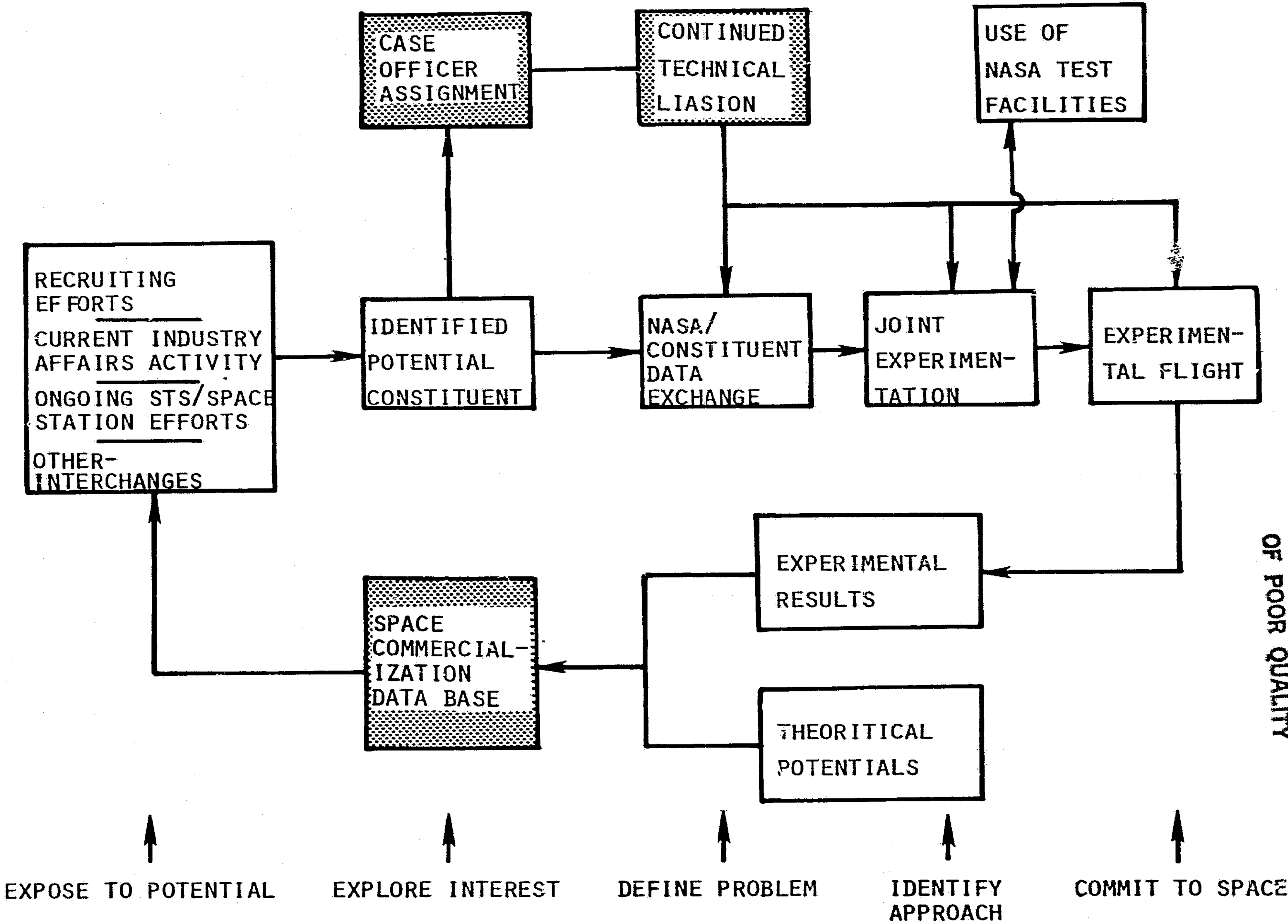


FIGURE 11 - 1

3. Define Problems - The third step requires a lengthy, in-depth technical exchange between NASA and the constituent Industry. These exchanges should, in all probability, be conducted at a NASA Laboratory and be tailored to the technological areas in which the industry is involved or interested. Specifically, the industry's level of technical expertise, current developmental progress, and future interests in specific scientific and/or technical topics, should be ascertained.

4. Identify Approach - Whereas the intent of Step 3 is to discover initial, common areas of interest and expertise, in Step 4 a joint scenario is investigated and planned. This mutually agreed-to approach should be as definitive as possible, including a clearly defined end-to-end program for experiments to be conducted on NASA facilites.

5. Commit to Space - This Step is, of course, the culmination of the process and the final objective of the Space Commercialization program. Care must be taken, however, not to begin this Step until the results of Step 4 are thoroughly evaluated. Proof of concept, in this context, requires that industries witness a careful approach to flight through cautious pre-flight procedures.

In summary, it is suggested that NASA management establish a process similar to the type discussed above, as a method for fortifying and demonstrating its intention of establishing a Space Commercialization Program. This suggestion is made with the knowledge that the process could be exercised among a number of industries simultaneously, in order to determine its effectiveness. This might be initiated as part of the follow-up Tasks of the Office of Industrial Affairs Commercialization Contract.

APPENDIX A

TABLE A-I

SUMMARY OF MPS INVESTIGATIONS

ORIGINAL PAGE IS
OF POOR QUALITY

CODE	TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	RESULTS
1	Ultrapure Glass Optical Waveguide Development in Microgravity by the Sol-Gel Process	Dr. S.P. Mukherjee Battelle Columbus Labs	Ground	June 1982 To June 1983	1) to study the homogeneity of gels and gel-derived in the oxide systems which are potentially important in the field of optical waveguild applications 2) to study the glass formation ability of certain compositions in the selected melting of homogenesis multi-component noncrystalline gels. 3) to study the influence of impurities obtained from the containers of the glass formation ability.	
2	Containerless High Temperature property Measurements by Atomic Fluorescence	Dr. P.C. Nordine Yale University	Ground	June 1980 To May 1983	To measure high temperature properties in containerless experiments using laser excited atomic fluorescence.	
3	Undercooling Studies in Metastable Peritectic Compounds	M.B. Robinson Marshall Space Flight Center	Ground	March 1979 To March 1982	To investigate undercooling and containerless solidification of metastable superconducting alloys Nb_3Ge and Nb_6Al and pure metal melts such as Nb.	
4	Free Cooling at High Temperature	Dr. L.A. Schmidt National Bureau of Standards		April 1981 Cont.	To derive analytical formulas that express the temperature dependent specific heat and emissivity as functions of the observed time-dependent surface temperature and rate of energy loss.	
5	Convection in Grain Refining	Prof. J. Szekely Prof. M.C. Flemings MIT		I	To obtain a better understanding of the relationship among fluid flow phenomena, nucleation, and grain refinement in solidifying metals both in the presence and in the absence of a gravitational field.	
6	The Upgrading of Glass Microballoons	Dr. Stanley A. Dunn Bjolksten Research Labs		August 1978 To August 1982	To study extensively the processes and mechanisms involved in producing glass microballoons of acceptable quality for laser fusion by gas jet levitation and manipulation in the molten condition.	
7	Electrostatic Control and Manipulation of Materials for Containerless Processing	Dr. D.D. Elleman Dr. W. K. Rhim Jet Propulsion Laboratory		October 1978	To develop electric field positioning/manipulation techniques and technology for the containerless processing of materials in bulk and dispersed forms.	

TABLE A-I (Continued)

8	Homogeneous Crystallization Studies of Glass Forming Systems	Dr. E.C. Ethridge Dr. P. Curreri Marshall Space Flight Center	April 1981 To April 1984	To use containerless as well as pseudo-containerless processing techniques to melt and resolidify borderline glass formers in such a way as to obtain critical cooling rates to avoid homogeneous crystallization
9	Rework of the SPAR Electromagnetic Levitator (EML) for Materials Experiment Assembly (MEA) Accommodation	Dr. R.T. Frost General Electric Co.	October 1981 To Oct. 1982	To study the upgrade requirements and approaches needed for incorporation of an EML in the MEA carrier, to design and develop an engineering version of multisample specimen exchanger, to develop and test improvements in high temperature drop calorimetry techniques including new techniques for low gravity work, and to carry out support tasks for the electromagnetic containerless processing Task Team.
10	Measurement of the Properties of Tungsten at High Temperatures	Dr. J. Margrave Rice University	Nov. 1978 To March 1985	The measurement of the thermophysical properties of tungsten and tantalum using containerless techniques.
11	Measurement of High Temperature Thermophysical Properties of Tungsten Liquid and Solid	Dr. D. W. Bonnell National Bureau of Standards		To evaluate experimental procedures used in the interaction between General Electric Advanced Application Laboratory (GE) and Rice University, to measure the high temperature enthalpy increments of liquid and solid Tungsten
12	Dynamic Thermophysical Measurements in Space.	Dr. A. Cezairliyan National Bureau of Standards	April 1981 Cont. Task	To develop techniques for the dynamic (subsecond) measurement of selected thermophysical properties (such as, heat capacity, heat of fusion, electrical resistivity) of solids and liquids at temperatures above 2000K in experiments to be performed near-zero-gravity environment.
13	Ultimate Intrinsic Coercivity Sm[illegible] Magnet	Dr. Dilip Das Charles Stark, Draper Laboratory Dr. R.T. Frost General Electric	Sept. 1979 To July 1982	To produce Sm-Co magnets of reasonably high maximum energy product with intrinsic coercivity.
14	Containerless Processing of Glass Forming Melts in Space	Dr. D. E. Day University of Missouri-Rolla	Feb. 1982 To Jan. 1983	1) To measure the effectiveness of containerless melting in extending the compositional limits for glass formation 2) to develop the processing procedures needed to produce multicomponent precursor specimens which will yield chemically homogeneous melts in microgravity and 3) assess the suitability of the flight hardware for levitating melts in microgravity. (Space Shuttle).

(TABLE A-1 (Continued)

15	Gel Precursors as Glass and Ceramic Starting Materials for Space Processing Applications Research	Dr. R. L. Downs W. J. Miller KMS Fusion, Inc.			To determine experimental procedures to produce gels starting materials for investigations of containerless processing in space.
16	Fluid Dynamics Numerical Analysis	Dr. L.W. Spradley Dr. J. Robertson Lockheed Missiles and Space Company		August 1979 To August 1982	To compute transient thermal convection for cases of importance to materials processing in space.
17	Theoretical Studies of the Surface Tension of Liquid Metals	D. G. Stroud Ohio State University		Feb. 1982 To Feb. 1984	To develop a theoretical understanding of the surface tensions of liquid metals, and of their temperature and concentration derivatives.
18	Physical Phenomena in Containerless Glass Processing	Dr. R.S.Subramanian Dr. R. Cole Clarkson College of Technology	Ground base	Dec. 1977 to Dec. 1982	To study the behavior of gas bubbles inside drops of model fluids and molten glasses in free fall, focusing on their migration and interaction
19	Kidney Cell Electrophoresis	Dr. Paul Todd Penn State Univ.		June 1980 Cont.	To repeat the MA-011 experiment under conditions which are optimum for the viability of human kidney cells and most favorable for the least possible electrophoretic separation of those few cells which produce urokinase or human granulocyte conditiong factor (HGCF), and erythropoitin.
20	Production of Large-Particle-Size Monodispersed Latexes in Microgravity	Lehigh Univ. J. Vanderhoft F.J. Micale M.S. El-Aasser		Feb. 1978 to Feb. 1983	To explore the possibility of preparing large particle-size monodisperse latexes in microgravity to avoid the problems of coagulum formation, as well as creaming and sedimentation, as the particles grow in size and change density.
21	Experimental and Theoretical Studies in Wetting and Multilayer Absorption	Dr. M.R. Moldover Dr. J.W. Schmidt Dr. J.W. Cahn National Bureau of Standards		April 1981	To use optical techniques to measure the thickness of the layer which intrudes between the upper liquid phase and the vapor at the liquid vapor interface above 3 different transparent binary solutions and one transparent tertiary solution
22	Biosynthesis/Separation Laboratory-Development of a Space Biosynthesis System and Biological Studies for Electrophoresis in Space	Dr. D.R. Morrison Mr. Bernard J. Mieszke		Jan. 1981 Cont.	1) To obtain data on the performance of cell culturevesse system elements to define the biological oxidational process—and 2) determine the limits of ground-base technology using a preprototype reactor for studying enzymatic reactions and suspension cell cultures.

ORIGINAL PAGE IS OF POOR QUALITY

(TABLE A-1 (Continued))

23	Mass Transfer in Electrolytic Systems Under Low Gravity Conditions	Dr. C. Riley et al University of Alabama Huntsville	Sept. 1979 To June 1982	The electroformation of materials with improved or more desirable properties and a better understanding of the transport of inert suspensions during the electrode position process.
24	Mathematical Models of Continuous Flow Electrophoresis	Dr. D.A. Saville, et.al. Princeton Univ.	August 1977 To Feb. 1983	A comprehensive model of the actual 3-b flow, temp. and electrical fields snall be developed to provide guidance in the design of electrophoresis chambers for specific tasks and means of interpreting test data on a given chamber.
25	Electrophoresis Technology	Dr. R. S. Snyder MSFC		1) To analyze the field flow and particle motions during continuous flow electrophoresis by experimentation and computation 2) characterize and optimize electrophoretic separators and their operational parameters, and 3) separate biological cells using apparatus that has been characterized or modified to perform in a predictable manner and according to procedures that have been developed to yield improved separation.
26	Aggregation of Red Cells	Dr. L. Dintenfass University of Sydney		To determine whether the size of red cell aggregates, kinetics and the morphology of these aggregates are influenced by near-zero gravity; whether viscosity, especially at low shear rate, is afflicted by near-zero gravity (the latter preventing sedimentation of red cells); whether the actual shape of red cells changes, whether blood samples obtained from different donors react in the same manner to near-zero gravity.
27	Transient Thermal Convection in Low-g	Dr. R.F. Dressler NASA HQ	Jan. 1980 Cont.	To obtain analytical solutions for transient and periodic convection flows for arbitrary low-g excitations with imposed thermal gradient in cylinders and cubes for both 2-b and 3D flows.
28	Surface Tensions and their Variations with Temperature and Impurities	S. C. Hardy National Bureau of Standards	April 1977 Cont.	Traditional sessile drop surface tension measurements are being used in conjunction with Auger spectroscopy and other modern surface analytic techniques to study the thermodynamics and chemistry of liquid metal interfaces.
29	New Polymers for Low-gravity Purification of Cells by Phase Partitioning	J. Milton Harris Univ. of Alabama Huntsville		To produce materials which will aid in space experiments, to separate important cell types and to study the partitioning process in the absence of gravity.
30	Purification and Cultivation of Human Pituitary Growth Hormone-Secreting Cells	W. C. Hymer Penn State Univ.	June 1981 To June 198_	To address the problem of a) separation of the pituitary growth hormone cell, b) its maintenance in vitro, and c) assessment of the role that gravity plays in establishing limits at these current lab technologies.

ORIGINAL PAGE IS OF POOR QUALITY

TABLE A-I (Continued)

31	Transient Convective Heat Transfer in Zero gravity	Dr. V. Arp Dr. R. Noble National Bureau of Standards Boulder, Colorado		To separate the gravitational contribution from other contributions to dynamic heat and mass transfer measurement, thus allowing a more accurate comparison with theory, leading to improved engineering correlations.
32	Hormone Purification by Isoelectric Focusing in space	Dr. Milan Bier Univ. of Arizona-Tucson	March 1978 To March 1982	To study the effects of gravity on the isoelectric focusing process; to define and produce a definite isoelectric focusing experiment, and to refine future isoelectric focusing technology.
33	Countercurrent Distribution of Biological Cells	Dr. D.E. Brooks Univ. of Oregon Health Sciences Center	Nov. 1979 To Nov. 1982	To develop and understand cell partition in a reduced gravity environment, as a sensitive, analytical and high resolution preparative procedure for biomedical research.
34	Blood Flow in Small Vessels	Dr. G. R. Cokelet Dr. H. Meiselman Dr. H. Goldsmith		To obtain ground-based data for establishment of flight test conditions and test potential flight experiment components; to study the flow of blood under low shear stresses in the red cell sedimentation.
35	Thermocapillary Flows and Their Stability: Effects of Surface Layers and Contamination	Dr. S.H. Davis Northwestern Univ.	June 1980 To June 1983	An understanding of the convection accompanying the process of growing high-quality crystals in a u-g environment
36	Directional Solidification of Magnet Composition	Dr. R.G.Pirich Grumman Aerospace Corporation	Feb. 1977 to Feb. 1983	To investigate the finer microstructure and enhanced magnetic properties of Mn-Bi eutectic directionally solidified in space.
37	Directional Solidification of Monotectic and Hypermontectic Aluminum-Indium Alloys under u-g	Dr. C. Potard Centre d'Etudes Nucleaires de Grenoble.	Sept. 1976 present	To analyze the mechanisms involved in the composite solid structure formation obtained from a miscibility gap alloy under microgravity.
38	Binary Miscibility Gap Systems	Dr. V.A. Schmid National Bureau of Standard	April 1981 Cont. Task	To exploit the thermocapillary migration effect in the design of a controllable heat valve which is the thermal analog of an electronic vacuum triode.
39	Modeling Directional Solidification	Dr. W. R. Wilcox Clarkson College of Technology	May 1982 To May 1985	To develop tools used in explaining results of directional solidification in space.

ORIGINAL PAGE IS OF POOR QUALITY

(TABLE A-I (Continued)

40	Study of Eutectic Formation	Dr. W. R. Wilcox Clarkson College			To investigate theoretically the influence of convection on lamellar spacing of a eutectic and to develop a technique for revealing the longitudinal microstructure of the MnBi-Bi eutectic.
41	Dendritic Solidification at Small Supercoolings	M.E. Glicksman Rensselaer Blytechnic Institute		March 1977 To June 1982	To obtain information relating to the kinetic and morphological behavior of systems solidifying at small supercoolings especially regarding the role of convective and diffusive transport and the influence of gravity.
42	The Influence of Gravity on the Solidification of Monotectic Alloys	Dr. A. Hellowell Michigan Technological Univ.		Sept. 1980 To Sept. 1983	To examine the monotectic reaction using directional solidification methods in order to obtain aligned composite structures.
43	Comparative Alloy Solidification	Dr. M.H. Johnston MSFC	Ground-base KC-135		To use transparent model systems to investigate the gravitational influence on the solidification process, of actual metallic systems
44	Aligned Magnetic Composites	Dr. D.J. Larson, Jr. Grumman Aerospace Corp.		July 1978 To July 1983	To contribute to understanding the role of convection on plane front solidification of eutectic and peritectic composites and the relationships between morphology and magnetic properties
45	Interfacial Destabilization in Metal Alloys	Y. Malmejac J. J. Javier Laboratoire d'Etudes de la Solidification Centre d'Etudes Nucleaires de Grenoble		Jan 1980 Cont. Risk	To study the destabilizing mechanisms that affect a crystal growth interface; to obtain information on destabilizing morphologies in the steady and transient states and on growth kinetics behavior; and to attempt to separate the influence of liquid phase instabilities from the interface instability.
46	Vapor Growth of Alloy-Type Semiconductor Crystals	Dr. Heribert Weidemier Rensselaer Polytechnic Institute		March 1978 To March 1983	To investigate through systematic ground based studies the effects of gravity driven convection on the growth of single crystals of alloy-types semiconductors; to define optimum conditions for the growth of these materials in a microgravity environment; and to perform crystal growth studies in space.
47	Heat Flow and Segration in Directional Solidification	Prof. Witt MIT			Directed toward the optimization of crystal growth and segregation during solidifaction in Bridgman-type configurations.
48	Vapor Phase of PbSnte	JA Zoutendyk Jet Propulsion Laboratory	Ground base	March 1981 To March 1982	The experimental study of gravity-driven convection effects in the growth of PbTe and cdte crystals by physical vapor transport.

TABLE A-I (Continued)

49	Studies of Model Immiscible Systems	D.O. Frazier et al MSFC	Oct. 1979 To Oct. 1982	To use model organic immiscible systems to obtain fundamental information applicable to two-phase systems in general, and to apply this understanding to materials of interest in the Materials Processing in Space Program in order to interpret results of flight experiments involving monotectic alloys.
50	Liquid Phase Miscibiltiy Gap Materials	S.H. Gelles, S.H. Gelles Assoc. A.J. Markworth, Battelle Columbus Labs	April 1978 To April 1983	To determine the manner in which the micro-structural features of liquid-phase miscibility gap alloys develop.
51	HgI_2 Crystal Growth for Nuclear Detectors	W. F. Schnepple Dr. L. Vandenberg EG&G, Inc.	April 1978 To April 1983	To obtain a benchmark quality sample grown at low-g conditions and to study vapor growth phenomena under space conditions
52	Direct Observation of Interface Stability	Prof. Tiller Prof. R.S. Flegelson Dr. D. Elwell Stanford Univ.	Dec. 1978 To Jan 1982	A careful test of theory with experiment on a model system with all the significant material parameters being measured for this system.
53	Float Zone Experiments in Space	Dr. J. D. Vethoeven Ames Laboratory Iowa State Univ.	Oct. 1981 To Oct. 1982	To determine if surface tension-driven convection in a float zone can be controlled or eliminated by means of surface film, and to investigate solute distribution and measure liquid diffusion coefficients in floating zones.
54	Defect Chemistry and Characterization of (HgCd) Te	Dr. H.R. Vydyanath Honeywell	Dec. 1978 To March 1982	To study the nature and concentration of the lattice defects incorporated into (Hgl-xCdx) te Alloys as a function of the physiochemical conditions of preparation.
55	Fluid Dynamics and Thermodynamics of Vapor Phase Crystal Growth	Dr. Herbert Wiedemier Rensselaer Polytechnic Institute	Jan. 1980 To Dec. 1982	To provide basic mass transport and crystal growth data which, combined with a thorough knowledge of the thermodynamics will improve the fluid dynamic characterization of vapor transport systems.
56	Advanced Methods for Preparation and Characterization of Infra-red-Detector Materials	Dr. J. G. Broerman et.al.,McDonnel Douglas Research Labs		To quantitatively establish the characteristics of Hg_1-x cdx Te as grown only on Earth (1-g) as a basis for subsequent evaluation of the material processed in space.
57	Solutal Convection and Its Effects on Crystal Growth and Segregation in Binary and Pseudo-Binary Systems with Large Liquidus-Solidus Separation	Dr. Edith D. Bourret MIT		Is concerned with a theoretical and experimental study of the effects of solutal convection on segregation in binary and pseudo binary systems with large liquidus-solidus separation (i.e. 6c-Si, Hg_1-xcdyte, $PbxSa_1$-yte)
58	Analysis of the Float Zone Process	Prof. R.A. Brown MIT		Is directed toward a fundamental understanding of the interaction of heat, mass, and momentum transfer in the floating zone method for growing single crystals from the melt.

TABLE A-1 (Continued)

59	Solutal Convection During Directional Solidification	S. R. Coriell R.S. Schaeffer National Bureau of Standards		To calculate and measure effects of convection caused by simultaneous temperature and concentration gradients on directional solidification, including determination of segregation effects in experiments done on Earth and estimation of the effect of microgravity and magnetic fields in avoiding such convection.
60	Semiconductor Material Growth in Low-G Environment	R.K. Crouch A. L. Fripp Langley Research Center		To utilize the microgravity environment of space to investigate the effect of convection on the homogeneity and perfection of compound semiconductor crystals.
61	Crystal Growth of Device Quality GaAs in Space	Prof. Gatos Dr. Jacek Lagowski MIT	April 1977 Cont.	To establish relationships among crystal growth parameters, materials properties, electronic properties and device applications of GaAs.
62	Microgravity Silicon Zoning Investigation	Dr. E.L.Kern, Consultant, G.L.Gill Westech Systems, Inc. Prof. Oscar Stafsudd, UCLA	July 1982 To July 1983	To grow uniform silicon crystals through the USC of microgravity conditions.
63	Solution Growth of Crystals in Zero-Gravity	Dr. R.B. Lal Alabama A&M University Dr. R.L. Kroes, MSFC	June 1978 To June 1983	To grow TGS crystals from aqueous solution in low-gravity; to investigate mass transport and heat flow in a diffusion-controlled growth system; to evaluate the feasibility, possible advantages and technical potential of producing solution growth crystals in space.
64	Growth of Solid Solution Crystals	Dr. S.L. Lehoczky, MSFC Dr. F.R. Szofran, MSFC Dr. L.R. Holland, UAH Dr. J.C. Clayton, Semtec Dr. D.C. Gillies, Semtec	Oct. 1977 To Oct. 1982	To determine the conditions under which single crystals of solid solutions can be grown from the melt in a Bridgman configuration with a high degree of chemical homogeneity.
65	Fluid Dynamics of Crystallization from Vapors	Dr. F. Rosenberger Univ. of Utah Salt Lake City	June 1978 Cont.	Obtaining fundamental insight into the complex physiochemical fluid dynamics of closed ampoule vapor crystal growth processes to the extent that a desired set of crystal growth conditions can be designed in advance.

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE A-I (Continued)

66	Crystal Nucleation in Glass Forming Alloy and Pure Metal Melts Under Containerless and Vibrationless Conditions	Prof. David Turnbull Harvard Univ.		June 1978 To Dec. 1982	To characterize nucleation behavior in glass-forming alloy melts.	
67	Fusion Target Technology	Dr. T.G. Wang Jet Propulsion Laboratory		Oct. 1979 Cont.	1) To study the physical processes that are associated with the fabrication of inertial confinement fusion (ICF) targets in a weightless environment, 2) determine jointly with DOE centers the need for extended O-g in future production of ICF targets. 3) provide technological information to DOE centers.	
68	Advanced Containerless Processing Technology	Dr. T.G. Wang Jet Propulsion Laboratory		October 1970 Cont.	1) Study contactless positioning and manipulation of a high temperature acoustic chamber. 2) provide design information on a flight version of this chamber 3) provide a set of ground-base facilities to perform precursor experiments.	
69	Multiple Materials Melting (metals)	L.I. Ivanov,et.al. Institute for Metallurgy USSR	Apollo-Soyuz		To utilize the low-g environment to reduce gravity-driven segregation effects in the synthesis of compound materials of significantly different specific gravity.	The kinetics of diffusion and phase formation in the solid W (WRe alloy) liquid A I diffusion area was approximately the same for both ground base and flight samples.
70	Germanium Silicon Solid Solutions	U.S.Zemskov et.al. Institute for Metallurgy USSR	Apollo Soyuz		To study the possibility of using micro-gravity conditions for obtaining solid solution monocrystals with uniformly distributed components.	The crystallization in low-g did not occur under the expected ideal stationary growth and segregation conditions. Convective mining was negligible in the low-g and graphite ampoule walls were not wet by the molten samples.
71	Chemical Foams	Dr. P.G. Grodzka Lockheed	Apollo-Soyuz Test Project		To investigate the stability of a liquid foam in the absence of liquid draining from thin walls.	Due to equipment malfunction no definitive data were obtained.
72	Liquids Spreading	Dr. S. Bouregeois Lockheed	Apollo-Soyuz Test Project		To investigate the spreading of liquids over solid liquid interfaces and to measure the shape of the spreading liquid and the rate of spreading.	Poor quality of the photography did not allow a definitive analysis to be made.
73	Capillary Wicking	A.F. Whitaker MSC	Apollo-Soyuz Test Project		To illustrate wicking action in weightless environment and to determine the efficiency of transfer and wicking rates of stainless steel wicks used for fluid management in spacecraft.	Wicking of both oil and water proceeded much faster in the ASTP than anticipated on the basis of ground tests and KC-135 flight tests. The liquid was observed to rise along the corner formed by Teflon support back and mesh.
74	Monotectic and Sytectic Alloys	Dr. L.L. Lacy, MSCF Dr. C. Young The Aerospace Corporation	Apollo-Soyuz Test Project		Low-g environment was utilized by this experiment to minimize buoyancy and convective influences which in normal gravity prevent adequate synthesis of material systems in which significant specific gravity differences exist.	The liquid-state homogenization of polycrystalline, multiphase A/sb in low-g produces major improvements in macroscopic and microscopic homogeneity, showing 4 to 20 times less of the unwanted secondary phase than in 1-g.

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE A-I (Continued)

75	Interface Marking in Crystals	Prof. H.C. Gatos A.F. Witt M. Lichtensteiger C.J. Herman, MIT	Apollo-Soyuz Test Project	To determine the growth rate during the solidification process by utilizing a novel electric pulsing system to mark the interface.	
76	Zero-G Processing of Magnets	Dr. D.J. Larson Grumman Aerospace Corporation	Apollo-Soyuz Test Project	To investigate the effects of reduction of gravitationally dependent elemental segregation and convection in the solidification of high-coercive-strength magnetic composites in low-g.	The array of MnBi crystals processed isothermally apparently resulted from edge-to-center gradients and produced no unusual magnetic effects.
77	Crystal Growth from the Vapor Phase	Dr. H. Wiedemeier et.al. Rensselaer Polytechnic Institute	Apollo-Soyuz Test Project	To study the growth of semiconductor crystals by chemical transport reactions using a vapor transport agent in a low-g environment.	No difference was found in the lattice parameters and the orientation of the native growth faces of the crystals formed in low-g and 1-g. The turbulent flow characteristic of 1-g growth did not exist in the low-g environment.
78	Halide Eutectic Growth	Dr. A. S. Yue et.al. UCLA	Apollo-Soyuz Test Project	To study the growth of LiF fibers.	Fiber length in portions of the low-g samples showed a many-fold increase over their 1-g fibers. Transmittance of the low-g fibers was reported to exceed that of the 1-g fibers by several fold over most of the wavelength band 4 to 10 μm.
79	Electrophoresis Demonstration	Dr. R.S. Snyder MSFC	Apollo 16 Apollo 17	To test the concept of using low-g to prevent unwanted convective flows from Joule heating static-column, free-flow electrophoresis, and to identify problems that may be encountered with bubble formation, nongravity-driven flows, and other problems encountered in space electrophoresis.	Sample bands were severely distorted by electrosmotic flows in both experiments; however, the experiments provided the impetus to develop special coatings to lower the zeta potential and eliminate such flows in future experiments.
80	Electrophoresis Technology	Dr. R.E. Allen MSCF Dr. C.H. Barlow Abbot Labs	Apollo-Soyuz Test Project	To demonstrate the feasibility of free-flow electrophoresis in a static column by using the low-g environment to suppress the convective mixing associated with joule heating.	Enhanced production of urokinase, erythropoietin, and granulocyte conditioning factors were found in the separate cell fractions, which hints that separation according to cell function was accomplished.
81	Electrophoresis	Dr. K. Hanning Max Planck Institute for Biochemistry, Munich	Apollo-Soyuz Test Project	To investigate and evaluate the increase in sample flow and sample resolution achievable in space.	Although there was a limited amount of data, there was an improvement with both the resolution and the throughput of continuous flow electrophoresis.
82	Crystal Growth	Dr. M.D. Lind Rockwell International Science Center	Apollo-Soyuz Test Project	To investigate the growth of single crystals of insoluble substances by a process in which reactant solutions are allowed to diffuse toward each other through a region of pure solvent.	Some crystals were larger than gel-produced in 1-g, some were plated-shaped and some were rhombohedral in shape. Birefringence was also exhibited by the low-g grown crystal of calcite.
83	Surface-Tension-Induced Convection	Dr. R.E. Reed Dr. Vollrath Dr. H.L. Adair Oak Ridge National Laboratory, Oak Ridge, Tenn.	Apollo-Soyuz Test Project	To investigate compositional induced surface tension-driven inwetting and nonwetting containers in a low-g environment.	Marangoni convection offers the best explanation for the observed distribution, and therefore the "non-slip" boundary condition apparently does not apply to nonwetting materials in low-g.

TABLE A-I (Continued)

84	Solidification of Liquid Miscibility Gap Aloys Under Free Fall	Dr. L.L. Lacy MSFC Dr. G. Otto University of Alabama in Huntsville	Drop Tower Experiment		To investigate the solidification of alloy systems that exhibit a liquid phase immiscibility gap.	Fine uniform dispersions of Ga-rich particles in a Bi matrix, obtained in the freefall solidification samples solidified under normal gravity, exhibit mass separation between the Bi and Ga. The unique microstructure obtained by low-g solidification caused the resistivity of the sample as a function of temperature to exhibit a unique behavior.
85	Surface Tension-Driven Flow in a Weightless Fluid	Dr. S. Ostrach Case Western Reserve University	Drop Tower		To obtain experimental data on surface-driven convection in the absence of gravity-driven flows.	Surface tension-driven flows can induce significant convection in a low-g environment.
86	Heat Flow and Convection Experiment	T.C. Bannister MSFC Dr. P.G. Grodzka, Lockheed	Apollo 14 Apollo 17		1) To determine to what extent contributions from residual vehicle accelerations and nongravity-driven convection affect heat transfer 2) to dramatize that convective flow can occur in the absence of gravity 3) to study the onset of unstable surface tension-driven convection in the absence of buoyance-driven convection.	On Apollo 14 the heat flow was 10 to 30% larger than predicted, which was due to crew-induced disturbances. On Apollo 17 heat flow agreed with predictions based on pure conduction.
87	Composite Casting Experiment	I.C. Yates, MSFC	Apollo 14		To investigate the possibility of forming various composite materials with large density differences from the melt.	The space processed samples did not exhibit the separation of phase experienced by the ground control samples. However, the distribution of the dispersed phase was not as uniform as expected. The paraffin-sodium acetate mixture formed a fairly uniform site composite.
88	Electrophoretic Separation Based on Immunomicrospheres	D. A. Rembaum Jet Propulsion Laboratory California Inst. of Technology Pasadena, CA			To demonstrate a new concept for cell separation based on labeling specific groups of cells with immunomicrospheres and isolating the labeled cells and unlabeled cells by means of electrophoresis; and, to demonstrate that cell separation of immunologically labeled cells is more efficient in the space environment than Earth.	
89	Glass Shell Manufacturing in Space	Dr. Robert L. Lolen KMS Fusion, Inc. Ann Arbor, Mich.		Dec. 1978 To Dec. 1981	To develop a detailed understanding of the chemical and physical processes involved in the formation of uniform, high-quality spherical glass shells.	
90	Directional Solidification of Misibility	Dr. M.H. Johnston Marshall Space Flight Center			To identify the influence of gravity on the aligned structure in liquid miscibility gap materials.	
91	Studies of Model Immiscible Systems	Dr. L.L. Lacy Marshall Space Flight Center		Oct. 1979 To Oct. 1981	To use model organic immiscible systems to obtain fundamental information applicable to materials of interest in the Materials Processing in Space program in order to interpret results of flight experiments involving monotectic alloys.	

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE A-1 (Continued)

92	Foam Copper	Prof. R.B. Pond J.M. Winter Marvaland, Inc. Westminster, Md.		April 1978 To Oct. 1980	To implement a microgravity experiment to determine if entrapping gas bubbles during solidification in microgravity will result in a metal "foam".	
93	Liquid Metal Diffusion in Solubility Gap Materials	Prof. R.B. Pond J.M. Winter Marvaland, Inc. Westminster, Md.		April 1978 To Sept. 1980	To verify or disprove the suspicion that determining diffusion constants of solubility gap liquid metals in one "g" experiments will lead to erroneous results due to density-driven convection motion.	
94	Fluid Dynamics of Crystallization from Vapors	Dr. F. Rosenberger University of Utah Salt Lake City		June 1978 To May 1981	The synthesis of ultrapure mercuric iodide and the vapor composition (stoichiometry) required for the growth of mercuric iodide high resolution detector crystals.	Numerical modeling of vapor transport in vertical ampoules has shown that diffusion fluxes establish density gradients normal to the main transport direction.
95	HgI2 Crystal Growth for Detectors	W.F. Schnepple Dr. L. Vandenberg EG&C Corp. Santa Barbara, CA.		April 1978 To April 1983	To obtain a benchmark quality sample grown at low-g conditions and to study vapor growth phenomena under space conditions.	
96	Growth of Solid Solution Crystals	Dr. L.R. Holland Athens State College Athens Alabama Dr. A.F. Witt MIT Dr. D.B.Schenk, BMD-ATC		Oct. 1977 to Oct. 1982	To determine the conditions under which single crystals of solid solutions can be grown, from the melt in a Bridgman configuration, with a high degree of chemical homogeneity.	
97	Marangoni Effect in Crystal Processing	Dr. Arthur Fowle A.D. Little Cambridge, MA Dr. A.F.Witt MFT	Skylab	March 1978 To Dec. 1980	Measuring the freezing interface morphology and the velocity and temperature fields on the surface of a molten zone in a cylindrical sample of gallium doped germanium in a crystal growing configuration.	
98	III-V Semiconductor Solid Solution Single Crystal Growth	Dr. E.R. Gertner Dr. M.D. Lind Rockwill International Downey, CA		April 1979 To Dec. 1980	To improve the quality of semiconductor substrate material used in epitaxial growth processes, since the quality of the epitaxial deposit is often limited by the quality of the substrate.	
99	Characterization of Semiconductor Materials	Dr. D.C. Gillies Universities Space Research Association Columbia, Md.		Oct. 1980 To Oct. 1981	To develop techniques for characterizing high-quality, solid solution, alloy type semiconductors for use of infrared detectors or as IR transparent substrates.	
100	Analysis of the Float Zone Process	Prof. R.A. Brown Mass. Institute of Technology Cambridge, MA Sponsor: NASA	Ground base		Directed toward a fundamental understanding of the interaction of heat, mass, and momentum transfer in the floating zone method for growing single crystals from the melt.	Results of this study are being used to describe radial and axial segregation in systems operating in low-g conditions but in the absence of surface.
101	Transient and Diffusion Analysis of HgCdTe	Dr. J. Creed Clayton Semtec, Inc. Huntsville, Ala. Sponsor: NASA			The goal of this effort is to analyze the directional solidification of the alloy systems HgCdTe in order to obtain optimim processing conditions for crystal growth.	

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE A-I (Continued)

102	Solution Growth of Crystals in Zero-Gravity	Dr. R.B. Lal Alabama A&M Univ. Dr. R.L. Kroes MSFC		June 1978 To June 1983	1) to grow TGS crystals from aqueous solution in low-gravity 2) to investigate mass transport and heat flow in a diffusion-controlled growth system, and 3) to evaluate the feasible advantages and technical potential of producing solution growth crystals in space.	
103	Aligned Magnetic Composites	Dr. D.J.Larson,Jr. Grumman Aerospace Corporation Bethpage, N.Y.		July 1978 To July 1983	To evaluate the impact of convection (thermal and/or solutal) or coupled convective/diffusive transport on the plane front solidification of contained binary magnetic composites.	
104	Advanced Methods for Preparation and Characterization of Infrared-Detector Materials	Dr. S.L. Lehoczky F.R. Szofran B.G. Martin McDouglas Research Laboratories St. Louis, Mo.		Dec. 1978 to Dec. 1981	To quantitatively establish the characteristics of Hgl-x Cdyte as grown on Earth (l-g)as a basis for subsequent evaluation of the material processed in space, and to develop experimental, theoretical, and analytical methods required for such evaluation.	
105	Epitaxial Growth of Single Crystal Films	Dr. M. David Lind Rockwell International Dr. R.L. Kroes, MSFC	SPAR	Oct. 1975 To May 1980	To grow exitaxial films of gallium arsenide by liquid phase epitax p(LPE) in low gravity and to compare them with films grown in normal gravity.	Epitaxial films of reasonably good quality and very nearly the thickness ($\approx$ 1 um) predicted for convection-free, diffusion-limited growth were produced.
106	Analytical Approach to Modeling of Heat Flow in Bridgman-Type Crystal Growth	Dr. R.J. Nauman Ms. Ernestine Cothran Marshall Space Flight Center, Ala		Oct. 1980 To May 1981	To develop an analytical approach to the modeling of heat flow in Bridgman-type crystal growth.	A one and two dimensional analysis has been developed.
107	Oxide Glass Processing in Space	Mr. R.A. Hoppe Rockwell International Space Division	Skylab		To highlight experimental work conducted over the years leading to the production of useful new optical glasses in space.	Recent experiments, which have resulted in the formation of 1/4 inch diameter glass samples from two compositions, suggest that containerless melting and cooling as envisioned for space operations is of real technological significance.
108	Immiscible Alloy Compositions	Mr. J.L. Reger TWR Systems Group Redondo Beach, CA 90278	Skylab		To thermally process ampoules containing materials exhibiting either liquid or solid state immiscibility in order to determine the possibility of bulk production in space.	Low gravity processing of materials processing liquid or solid immiscibility can produce compositions exhibiting unusual metallographic and electronic behavior.
109	Silver Grids Melted in Space	Prof. E. Aernoudt Catholic Univ. Leuven, Belgium	Skylab		To make a preliminary study of the behavior of porous material when melted and resolidified in weightless condition.	1) Original porosity disappeared during the melting stage. 2) Stage is [illegible] solidification. 3) Leveling out of impurity concentration gradients appears to be slow in molten metal.

TABLE A-1 (Continued)

110	Preparation of Silicon Carbide Whisker Reinforced Silver Composite Material in a Weightless Environment	Tomoyoski Kawada National Research Institute for Metals 2-3-12, Nakameguro Meguro-ku, Tokyo, Japan	Skylab		To obtain Ag and SiC whisker composites with high density and uniform distribution of whiskers by heating and pressurizing sintered products above the melting point of Ag in a weightless environment.	Skylab samples differed from groundbased test sample, in uniform distribution of hardness values and the nonexistence of any floating whiskers.
111	Vapor Growth of IV-VI Compounds	Prof. Wiedemeier Rensselaer Polytechnic Inst. Troy, New York 12181 c/o Dept. of Chemistry	Skylab		To establish the positive effects of microgravity on crystal growth and fundamental properties of the vapor transport experiments.	The combined results confirm the unique conditions of weightlessness for materials processing and for the observation of basic transport phenomena.
112	Seeded, Containerless Solidification of Indium Antimonide	Dr. J.U. Walter University of Alabama in Huntsville Sponsor: NASA	Skylab		To investigate the feasibility of containerless processing of single crystals in space; obtain information on such crystals; and demonstrate potential of space for producing them.	Crystal facets appear as well-developed growth facets consistent with the crystalline symmetry of the material and are essentially optically flat. X-ray topographic analysis shows no evidence of grain boundary defects on the facets, indicating a high degree of crystalline perfection.
113	Exothermic Brazing	Mr. J.R. Williams Process Engineering Lab. Marshall Space Flight Center Alabama 35812	Skylab	June 12, 13 1973	To evaluate brazing as a tube joining technique for the assembly and repair of hardware in space, and to study the spreading, mixing and capillary action of molten braze material in near zero gravity.	Brazing in [illegible] is feasible. The zero-gravity environment resulted in several differences: increased solubility, increased liquid spreading, more uniform menisci (liquid/vapor interface) and a reduction of braze alloy shrinkage defects.
114	Metals Melting	Mr. E.C. Mc Kannan MSFC Alabama 35812	Skylab	June 1973	To study the behavior of molten metal; to characterize metals melted and solidified in the low-gravity space environment; and to determine the feasibility of joining metals in space.	Electron Beam welding, cutting and melting can be done in low-gravity. Solidification of specimens in a low-gravity environment were characterized by small, equiaxed grains in symmetric subgrain patterns.
115	Sphere Forming	Dr. D.J. Larson Grumman Aerospace Bethpage, New York 11714	Skylab	During Skylab II	To study the effects of weightlessness in solidification processess.	There was an outstanding record of both initial and terminal solute redistribution processes. The last regions to solidify evidence extensive solification terracing.
116	Zero Gravity Flammability	Mr. J.H. Kimzey Johnson Space Center Houston, TX. 77058	Skylab 4	Feb 4, 1974	To note the extent of surface flame and propagation and flash-over to adjacent materials, rates of surface and bulk flame propagation, self-extinguishment and extinguishment by both vacuum and spray water.	1) Burning rates were significantly reduced 2) Surface burn was not followed by continued inward burning. 3) Ignition and extinguishment were similar to one-g. 4) Typical blue flame and smoke patterns were noted.

TABLE A-1 (Continued)

117	Steady State and Segregation Under Zero Gravity InSb	Prof. A.F. Witt MIT Cambridge, MA 02139	Skylab	To confirm advantages of zero gravity environment; to obtain basic data on solidification; to explore the feasibility of electronic materials processing in outer space.	Proved the advantageous conditions provided by outer space on obtaining fundamental data on solidification.
118	Directional Solidification of InSb Alloys	Prof. W.R. Wilcox Univ. of Southern California Los Angeles, CA. 90007	Skylab	To investigate whether grain in indium antimonide crystals are generated by the compositional variations arising from hydrodynamic fluctuations in the melt.	Solidification experiments performed on InSb - GaSb alloys in both space and on Earth showed no dramatic differences in grain size; however, several interesting phenomena were discovered.
119	Influence of Gravity-Free Solidification on Microsegregation in Germanium	Dr. J.T. Yue Texas Instruments, Inc. Dallas, Tx. 75222	Skylab #2	Designed to characterize the influence of gravity-free solidification on the micro-segregation of a semiconductor material.	1) The solute boundary layer at the growth interface in space is correspondingly thinner. The solidification interface is significantly smoother and is found to be initially [illegible] toward the melt into space.
120	Radioactive Tracer Diffusion	Dr. A.O. Ukanwa Howard University Washington, D.C. 20001	Skylab #3 1973	To determine, in a convection-free environment, the self-diffusion coefficients for zinc and to estimate the reduction in convective mixing in Earth gravity by going into the zero-gravity environment of space.	An equation was determined for self-diffusion coefficient in liquid zinc. Complications arising from convection in liquids during mass transfer on earth may be avoided or minimized by utilizing the zero-g environment.
121	Copper-Aluminum Eutectic	Mr. E.A. Hoemeyer MSFC	Skylab	To show that an improved structure of lamellar eutectics could be grown in the absence of gravity induced thermal convection.	Specimens processed in zero gravity are superior to ground-base specimens on the basis of two characteristics: the defect spacing in lamellar widths is 12% better; the fault density is 20% less.
122	Metal and Halide Eutectics	Dr. A.S. Yue U.C.L.A. Los Angeles, CA 90024	Skylab	To prepare fiberlike NaCl-NaF eutectic with continuous NaF fibers embedded in a NaCl matrix and to measure the relevant optical properties of space-grown and earth-grown eutectics.	Continuous NaF fibers were produced due to the absence of convection current in the liquid during solidification. Larger transmittance over a wider wavelength was obtained from Skylab grown ingots. This is due to excellent alignment of NaF fibers embedded in the NaCl matrix.
123	Electromagnetic Containerless Melting and Solidification in the Weightless Environment	Dr. R.T. Frost General Electric, Philadelphia, Pa. 19101	Skylab	To indicate general facility concepts capable of processing the widest range of of possible important containerless processing experiments within reasonable technology constraints.	
124	Acoustic Positioning for Containerless Processing	Dr. R.R. Whymark Intersonics Inc. Chicago, Ill. 60611	Skylab	To describe a new type of acoustic position control system that can be adapted to space processing chambers with minimum modification to the chambers.	The acoustic energy well levitator is capable of levitating and positioning liquids and solid dense materials of sizes useful in space processing experiments.

(TABLE A-1 (Continued)

125	Acoustic Chamber Processing	Dr. T.G. Wang Jet Propulsion Laboratory	Skylab		To describe an acoustical method that can control any molten material within a container in a space environment.	By readily levitating, positioning, and manipulating materials placed in it, the acoustical resonator can serve a variety of space processing operations, such as drawing crystals, degassing and stirring of melts and castings.
126	Fluid Motion in a Low-G Environment	Dr. P.G. Grodzka Lockheed Missiles and Space Company	Skylab		To review the state of knowledge of fluid motions in low-g environments.	
127	Role of Gravity in Preparative Electrophoresis	Mr. R.S. Snyder MSFC Alabama 35812	Skylab		To review the current SOA in electrophoresis, with particular emphasis on the role of gravity and the use of istachophoresis.	The sharpness and self-restoring properties of boundaries in isotachophoresis make it an attractive candidate for space applications.
128	Preparative Electrophoresis of Living Lymphocytes	Dr. C.J. van Oss State Univ. of NY Buffalo 14214	Skylab		To develop the methodology for electrophoretic cell separation in space by first working out a methodology at gravity=1.	Both descending and ascending electrophoretic lumphocyte separation at gravity=1 show the possibilities as well as the probable limits to lymphocyte electrophoresis on earth.
129	Studies of Liquid Floating Zones	Dr. J.R Carruthers Bell Laboratories Murray Hill, NJ 07974	Skylab II		To examine the stability constraints imposed on the liquid zone in zero gravity so that crystal growth and purification processing methods may be developed for preparation of reactive material in future space flights.	
130	Particle Dispersion In Liquid Metal	Dr. J. Root General Dynamics/Convair San Diego, CA 92112	Skylab		To attain mixtures of liquid metals and solid particles which are free of solids and stabile.	For the successful preparation of composite materials by liquid-state processing in low-g environments, two requirements are fundamental: 1) complete wetting between the component materials during the liquid processing cycle; 2) maintenance of a uniform dispersion.
131	Solidification Studies of Nb-Ge Alloys	L.L. Lacy, et.al. Exxon Corporation Houston, TX Sponsor: NASA	Drop Tower	11/81	To investigate the solidification of Nb-Ge alloys after deep undercooling.	Samples have been supercooled as much as 500°K below the liquidus by using free-fall conditions to eliminate crucible-induced nucleation. Final microstructures are dependent on the quenching rates at the bottom of the drop tube -- a striking extension of the B phase solubility limit.

ORIGINAL PAGE IS OF POOR QUALITY

APPENDIX B

APPENDIX B

BIBLIOGRAPHY

Agarwal, P., R.F. Bunshah, and A.L. Bevolo. 1980. Ultrapure metals preparation in space. Final Report, NAS 8-33115. NASA Marshall Space Flight Center, Alabama.

Brown, R.L., and L.K. Zoller. 1981. Avenues and incentives for commercial use of a low-gravity environment. NASA Technical Paper 1925. NASA Scientific and Technical Information Branch.

Covault, C. 1982. Payload tied to commercial drug goal. Aviation Week and Space Technology (May 21 issue).

Craven, P.D. (ed.). 1978. Spacelab mission I experiment descriptions. NASA TM-78173. Marshall Space Flight Center, Alabama.

Firestone, R.F. and S.W. Schramm. 1978. Space processing of chalcogenide glass. Final Report, NAS 8-32388. NASA Marshall Space Flight Center, Alabama.

Flanagan, D. (ed.). 1967. Materials. W.H. Freeman and Company. San Francisco.

Gatos, H.C., J. Lagowski, and L. Jastrzebski. 1979. Present Status of GaAs. NASA CR-3093. NASA Scientific and Technical information Branch.

Gelles, S.H., E.W. Collings, W.H. Abbott, and R.E. Maringer. 1977. Analytical study of space processing of immiscible materials for superconductors and electrical contacts. NASA CR-150156. NASA Marshall Space Flight Center, Alabama.

Lacy, L.L., M.B. Robinson, T.J. Rathz, N.D. Evans, and R.J. Baywzick. 1981. Solidification studies of Nb-Ge alloys at large degrees of super cooling. Preprint series 81-102. Space Sciences Laboratory, Marshall Space Flight Center, Alabama.

BIBLIOGRAPHY (Continued)

McKannan, E.C. 1981. Survey of the U.S. materials processing and manufacturing in space program NASA TM-82427. Marshall Space Flight Center, Alabama.

Marshall Space Flight Center, Alabama. 1983. Commercial materials processing in low-g (MPLG) -- overview of commercialization activities. Briefing presented to NASA Headquarters, March 7, 1983.

Marshall Space Flight Center, Alabama. Proceedings of the third space processing symposium -- Skylab results (2 volumes). NASA.

Marshall Space Flight Center, Alabama. 1981. Materials processing in space (MPS) program description. NASA TM-82410. NASA.

Naumann, R.J. 1978. Descriptions of experiments selected for the space transportation system (STS) materials processing in space program. NASA TM-78175. Marshall Space Flight Center, Alabama.

Naumann, R.J. (ed.). 1979. Descriptions of space processing applications rocket (SPAR) experiments. NASA TM-78217. Marshall Space Flight Center, Alabama.

Naumann, R.J. 1979. Early space experiments in materials processing. NASA TM-78234. Marshall Space Flight Center, Alabama.

Naumann, R.J. and E.D. Mason. 1979. Summaries of early materials processing in space experiments. NASA TM-78240. Marshall Space Flight Center, Alabama.

Pentecost, E. 1981. Materials processing in space: a survey of referred open literature publications. NASA TM-82425. Marshall Space Flight Center, Alabama.

Pentecost, E. 1981. Materials processing in space program tasks. NASA TM-82443. Marshall Space Flight Center, Alabama.

Pentecost, E. 1982. Materials processing in space bibliography. NASA TM-82466. Marshall Space Flight Center, Alabama.

Pentecost, E. 1982. Materials processing in space program tasks. NASA TM-82496. Marshall Space Flight Center, Alabama.

Pentecost, E. 1983. Materials processing in space bibliography -- 1983 revision. NASA TM-82507. Marshall Space Flight Center, Alabama.

Robinson, M.B. 1981. Undercooling measurement in a low-gravity containerless environment. NASA TM-82423. Marshall Space Flight Center, Alabama.

Watts, C. 1982. Space factories a longways off. High Technology 2 (b) 23-26.

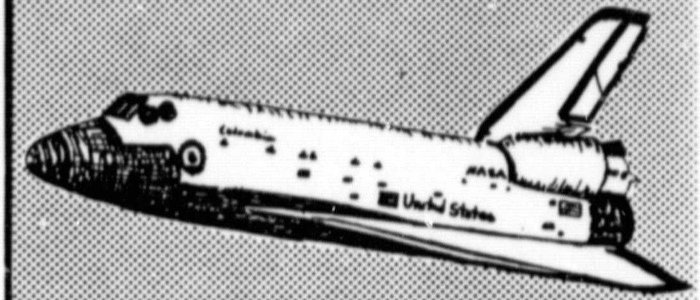
Waltz, D.M. 1981. Is there business in space? Presented to AIAA Annual Meeting and Technical Display. Long Beach, California.

APPENDIX C

APPENDIX C

BROCHURE

The following enclosure, Commercial Development in Space, A Prospectus, represents recommended material for inclusion in a brochure for use in discussions with industrial organizations considered to be potential space commercialization user industries. The format, which is essentially suggestive in nature, is currently under review by NASA Headquarters.



COMMERCIAL PRODUCT DEVELOPMENT IN SPACE

A PROSPECTUS

PURPOSE

Potential users need to be aware of the findings thus far, and of the prospects for the future, in order to assess their own opportunities for improved or new processes and products.

Since 1974, the U.S., European, Soviet Space Programs have explored use of the space environment for researching new ways for producing materials, with encouraging results.

As the costs of operating in space continue to fall, the development of materials with unique properties not achievable on earth is rapidly approaching commercial practicability. The space environment is already a proven arena for experimentation into materials processes difficult or impossible to achieve on earth: in the near future it can become an important complement to terrestrial industrial operations.

SPACE COMMERCIALIZATION

Creation of advanced technologies to cope with the space environment has been a driving requirement of the space program.

Spinoffs from these technologies permeate modern life:

- The pervasiveness and accuracy of present-day weather prediction, high seas navigation, resource location, related public services would be unattainable without satellites

- Improvements in electronics, cryogenics, computer programming, turbine technology alone have contributed in excess of $12 billion to the nation's GNP

- The thousand-fold increase of life and millionfold decrease in size of electronic components in the last two decades is rapidly leading to the computer society

Several of the most promising among these technologies were seized upon early in their development stage and brought to commercial fruition by industrial entrepreneurship.

- The revenues of the space communications industry, non-existent in 1964, were \$3.5 Billion in 1980; \$12 Billion forecast for 1990

- Other evolving commercial enterprises are private space launchers, earth observation services, space services for hire

The latest commercial opportunity is the exploitation of the space environment:

- For improving the quality of products and processes currently achievable in the ground environment

- For developing/manufacturing materials and products unattainable in the present ground environment

APPLICATIONS OF MATERIALS PROCESSING IN SPACE

THE CONCEPT — Control of the properties of materials has been the key to producing quality products since historical times.

Modern materials technology aims at generating products with ever improving characteristics of high purity, enhanced strength, precise shape, exact composition; and at attaining these characteristics at economically competitive costs, i.e., through processes providing the highest feasible yield.

Various industrial processes are affected by weight or by the consequences of weight, such as convection, separation of components. When performed in space, free from the tug of gravity, such processes are conducive to achieving highly controlled characteristics of the resulting materials.

In space, because the object being processed is weightless, it will stay put. No restraining container is required and contamination from confining walls can be avoided.

Numerous industrial processes exploit vacuum to achieve levels of cleanliness through evaporation and dissipation of contaminants. The extreme vacuum of space and the possibility of long exposure are conducive to high degrees of cleanliness.

ENVIRONMENTAL PROPERTY	BEST CURRENTLY ACHIEVABLE ON EARTH	ACHIEVABLE IN SPACE
LOW GRAVITY (MILLIONTHS OF EARTH GRAVITY)	• 100 FOR 40 SECONDS • 10 FOR 5 SECONDS	• 100 FOR WEEKS • 10 FOR DAYS • 1 FOR HOURS
HIGH VACUUM (FRACTION OF EARTH SURFACE PRESSURE)	• 10^{-17} FOR HOURS • VOLUME 25 LITERS	• 10^{-18} FOR MONTHS • VOLUME UNLIMITED

THE TABLE COMPARES ENVIRONMENTAL PROPERTIES AVAILABLE IN SPACE WITH THOSE AVAILABLE ON EARTH

Low gravity and vacuum, singly or in combination, provide the materials industry two principal opportunities:

- The investigation of the properties of materials under exceptional conditions, difficult of impossible to achieve on Earth

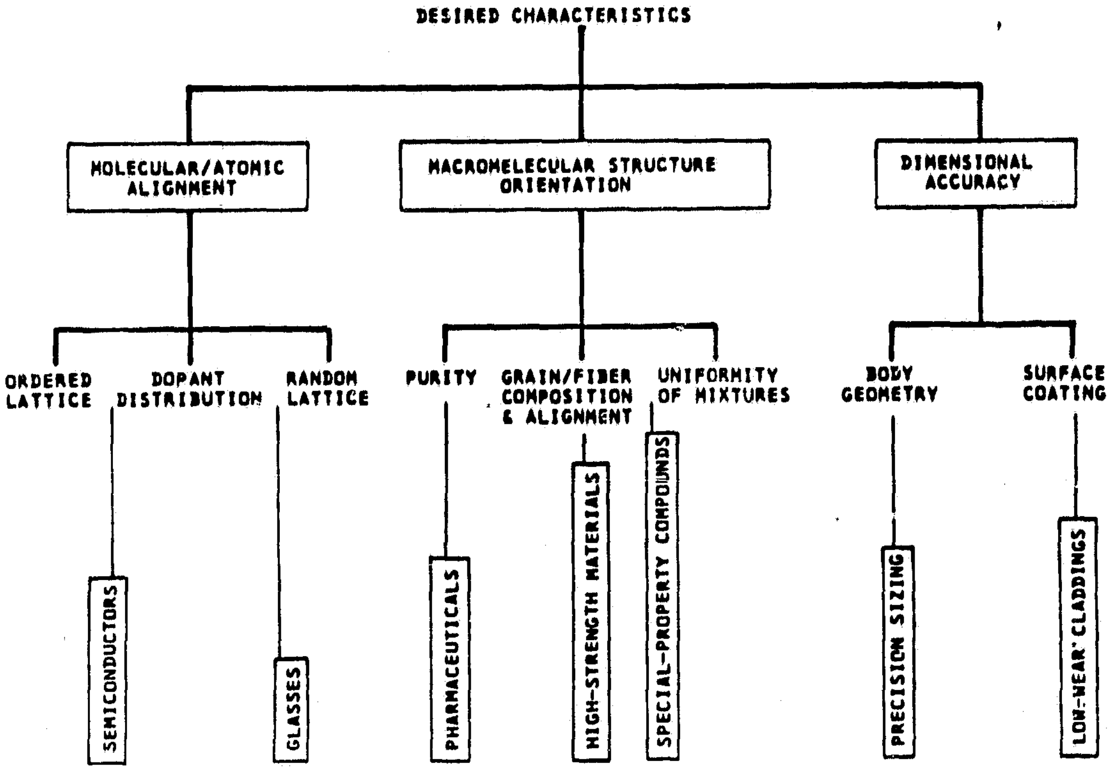
- The formulation of materials having unique properties

Both these opportunities can be exploited to:

- Better understand the mechanisms of materials formation and behavior for the purpose of developing improved or new processes usable on Earth

- Exploit space itself as a facility wherein to manufacture special products of high value per unit weight

Control of the properties of materials is effected at three levels.



The most desirable, but also the costliest, is control at the level of single molecules or atoms. This is essential, for example, in the manufacture of microelectronics.

Easier to achieve, more widely used because more economical, is control of the composition and orientation of aggregates of molecules. For example, control of extraneous substances is the key to purity; control of the composition of grains is important for abrasion wear; control of the alignment between grains or fibers is crucial to strengh.

Learning how to control product dimensions at competitive costs is important to most high-technology products and processes.

PROGRESS THUS FAR — Over 50 tests and experiments oriented to control of materials characteristics have been performed on NASA low gravity and/or vacuum facilities. Approximately 20 U.S. industries have and are participating in the program.

While most details are proprietary, names and objectives of the major industrial participants are available.

INDUSTRY	TYPE OF INVESTIGATION	COMMERCIAL OBJECTIVE
GRUMMAN	ALIGNED MAGNETIC COMPOSITES	IMPROVED MAGNETIC MATERIALS
INT. NICKEL	ELECTRODEPOSITION	ABRASION-RESISTANT COATINGS
JOHN DEERE	GRAPHITE FORMATION IN CAST IRON	HIGHER STRENGTH CASTINGS
MARVALAND INC.	FOAM COPPER ALLOYS	HIGH-STRENGTH STRUCTURES
MRA	GROWTH OF GALLIUM ARSENIDE	IMPROVED GAIN AND YIELD OF SEMICONDUCTORS
JOHNSON & JOHNSON	ELECTROPHORETIC PROCESSING OF BIOCHEMICALS	PURE DRUGS AT HIGH YIELDS
WANG	FORMATION OF GLASS SPHERES	IMPROVED TARGETS FOR TRIGGERED FUSION
BATTELLE	ULTRAPURE GLASS CONDUCTORS	IMPROVED FIBER OPTICS
GTI	METALLURGY	UNDERSTANDING OF GRAIN FORMATION
ROCKWELL	FLUIDS BEHAVIOR	UNDERSTANDING OF MELTING AND SOLIDIFICATION PROCESSES

INDUSTRY PARTICIPATION

FACILITIES — Short-duration tests at low cost are feasible on NASA's ground facilities. Longer periods of experimentation in an environment closely approaching the ideal are available on the Space Shuttle. Utimately, the Space Station, currently in the planning stage, will allow materials development and production activities for prolonged time periods and in significant quantities.

FACILITY	DURATION	AVAILABILITY
DROP TOWER	3 SECONDS	CURRENT
AIRCRAFT	40 SECONDS	CURRENT
ROCKET	3 MINUTES	CURRENT
SHUTTLE	4 DAYS	CURRENT
SPACE STATION	MONTHS	FUTURE

TERMS — Transfer of technology is a Congressional mandate to NASA.
Thus NASA must and will entertain arrangements with industry in the area of materials processing in space.

While the terms are highly flexible and can be individually tailored to the needs of each interested industry, their structure is based on three types of arrangements:

- Technical Exchange Agreements allow industries to cooperate with NASA in ground-based research and analyses; and to have access to NASA's results, facilities, personnel — as long as non-proprietary to other industries.

- Industrial Guest Investigator arrangements contemplate the appointment by industry of a technical expert to collaborate with NASA experts on a flight experiment.

- In Joint Endeavors, industry and NASA share the effort and costs of a complete program, from feasibility study through flight tests to demonstration.

Negotiated terms include

- Protection of proprietary industrial information

- Industry rights to patents

- Provisions for exclusivity

- Others, negotiated case by case

NASA advisory services are available to industries interested in structuring cost effective programs of investigation, experimentation and test.